AD 681932

FINAL REPORT

DAMAGE TO THE BASIC CHEMICAL INDUSTRY FROM NUCLEAR ATTACK AND RESULTING REQUIREMENTS FOR REPAIR AND RECLAMATION

PREPARED FOR:

STANFORD RESEARCH INSTITUTE
Menlo Park, California

and

OFFICE OF CIVIL DEFENSE
Washington, D.C.

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DAMAGE TO THE BASIC CHEMICAL INDUSTRY FROM NUCLEAR ATTACK AND RESULTANT REQUIREMENTS FOR REPAIR AND RECLAMATION

Final Report

June 1968

by

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William H. Van Horn
Milton Staackmann

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Burlingame, California

Prepared for

OFFICE OF CIVIL DEFENSE
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Summary
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Summary Report

of

DAMAGE TO THE BASIC CHEMICAL INDUSTRY FROM NUCLEAR ATTACK AND RESULTANT REQUIREMENTS FOR REPAIR AND RECLAMATION

THE PROBLEM

The continued survival of the population after a nuclear attack is closely related to the economic and technological recovery of the country. The basic elements of survival during the recovery period are dependent on the capability of a number of basic industries to survive or, at least, recover quickly from the effects of the attack. Since chemicals are used in almost all phases of material production and product manufacture, the chemical industry will have an especially important role in postattack recovery. In recognition of the importance of the basic chemical industry in the postattack period, the Office of Civil Defense and Stanford Research Institute have funded the present study to examine damage to the industry following nuclear attack.

OBJECTIVES

The objectives of this study were as follows:

1. Identification and characterization of the major unit operations or the processes commonly used by the SIC Group 281 industries (i.e., the basic chemical industry).

2. For each process identified, analysis of the physical damage expected to result from various overpressure ranges produced by a megaton-range weapon.

3. For each selected process and for each level of damage, preparation of repair estimates which include time, manpower, by skill, and support equipment.

4. Using the damage and repair results for the selected processes, synthesis of case studies of selected industries showing:

    a. Probable overall damage at various levels of attack

    b. Associated repair requirements

c. Time-phased sequence of repair operations

d. Alternate modes of operation

PROCEDURE

The procedures followed were:

1. Detailed functional descriptions were developed for five "typical" chemical plants (chlorine-caustic, oxygen, ethylene, sulfuric acid, and ammonium nitrate). These plants are representative of the many types of plants found within the SIC 281 group.

2. Elements or components employed in one or more of the "typical" plants were identified and characterized.

3. Damage to the various elements was estimated for a range of weapon effects and intensities; all weapon effects were keyed to overpressure.

4. Repair time and effort requirements were estimated for each critical element. Repair efforts for individual components were then summarized to obtain the repair effort for each typical plant.

5. The results of the repair estimates were analyzed, and a mathematical model was developed to relate damage (expressed as overpressure) to repair effort (in man-days).

6. Using the mathematical model, repair estimates were prepared for each subindustry (SIC 281X) and for the entire industry (SIC 281).

7. The time-phased repair effort was determined for each subindustry and for the entire industry including requirements for time, manpower (by skill), and supplies; alternate operating procedures which might alleviate constraints created by shortages of resources were also considered.

MAJOR FINDINGS

The major findings of the report are:

- The damage/repair catalog for chemical equipment which was developed as a result of the study provides the basis for estimates of the repair requirements for establishments of the basic chemical industry. It appears possible to use such a catalog for repair estimates of a wide range of industries outside the SIC 281 group by the addition of appropriate equipment.

- The calculated estimates of equipment repair for the various damage levels can be represented by a mathematical model which also reflect changes in equipment size or capacity. Appropriate models were developed to relate repair effort to damage level for the basic chemical establishments, industries, and the whole industry group.

- The repair effort required for restoration of equipment used in the basic chemical industry generally reflects the complexity and vulnerability of the equipment. The least vulnerable equipment items (those requiring the least repair effort) were those in which little internal damage occurred and the resultant repair required only realignment or resetting on foundations.

- The "worst case" repair effort required for the basic chemical industry could over-whelm the existing capability. It was estimated that the "normal" annual construction capability of the chemical industry is equivalent to only 20 percent of the estimated maximum repair effort (13.2×10^6 man-days for the SIC 281 industry for an overpressure of 25 psi).

- It appears that the supply of certain labor skills would be inadequate to meet the requirements for repair effort in the basic chemical industry in the postattack period. However, the existence of many persons with latent skill in the required categories may help in meeting the demand.

- The basic chemical industries are concentrated in the vicinity of standard metropolitan statistical areas (SMSAs), with over 70 percent of the industry production capability located within SMSAs.

- The more modern basic chemical establishments, which depend on automation and computer control systems, appear to have greater vulnerability to nuclear attack.

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Work Unit 3311B

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ABSTRACT

ABSTRACT

This study for the Office of Civil Defense identifies the major equipment components commonly used by industries of the basic chemicals group [Standard Industrial Classification (SIC) 281], estimates damage to the equipment components as a result of various nuclear weapon effects, and estimates the consequent repair requirements. Case studies for selected industries were synthesized by assembling the damage and repair estimates for the equipment components of various chemical establishments. These estimates were then scaled up to represent damage/repair for the selected chemical industries. Mathematical models were developed to relate repair effort with damage level for the individual equipment, establishments, industries, and the overall basic chemical industry group. From the output of the models, time-phased repair effort (with delineation of manpower by skills) was derived. The major findings of the report are:

- The damage/repair catalog for chemical equipment was crucial to the study results as it was the basis for estimates of the repair requirements for establishments of the basic chemical industry. It appears possible to use such a catalog for repair estimates of a wide range of industries outside the SIC 281 group by the addition of appropriate equipment.

- The calculated estimates of equipment repair for the various damage levels were represented by a mathematical model which also reflected changes in equipment size or capacity. Appropriate models were developed to relate repair effort with damage level for the basic chemical establishments, industries, and the whole industry group.

- The repair effort required for restoration of equipment used in the basic chemical industries generally reflects the complexity and vulnerability of the equipment. The least vulnerable equipment (those requiring the least repair effort) were those in which little internal damage occurred and the resultant repair required only realignment or resetting on foundations.

- The repair effort required for the basic chemical industries could overwhelm the existing capability. It was estimated that the "normal" annual construction capability of the chemical industry is equivalent to only 20% of the estimated maximum repair effort (13.2×10^6 man-days for the SIC 281 industry for an overpressure of 25 psi). (In four cases, the maximum repair estimates were shown to approximate or exceed new construction effort. This indicates that the study results are realistic—or even conservative.)

- It appears that the supply of certain labor skills would be inadequate to meet the requirements for repair effort in the basic chemical industries in the postattack period. However, the existence of many persons with latent skill in the required categories may help in meeting the demand.

- The basic chemical industries are concentrated in the vicinity of standard metropolitan statistical areas (SMSAs) with over 70 percent of the industry production capability located within SMSAs.

- Some of the more modern basic chemical establishments appear to have greater vulnerability to nuclear attack because of their dependence on automation, computer control systems, and in some cases, on interconnecting pipelines with related establishments.

Recommendations for future work include:

- Application of the results of this study to a large multichemical plant complex or to the Five-City Study.

- Exploration of the application of the study results to other industries.

- Examination of the effects of varying demand for chemical products after nuclear attack and the resultant changes in basic chemical industry repair requirements.

- Conduct of an in-depth study of the geographical distribution of establishments within the basic chemical industries.

- Incorporation of the study results into the National Entity Survival (NES) Study model.

INTRODUCTION

INTRODUCTION

The Problem

The continued survival of the population after a nuclear attack is closely related to the economic and technological recovery of the country. The basic elements of survival during the recovery period include not only food, clothing, and shelter, but water, pharmaceuticals, disinfectants, soaps, and other health-related materials. The production of safe, adequate supplies of basic survival materials is dependent on the capability of a number of industries to survive or, at least, recover quickly from the effects of the attack.

Since chemicals are used in almost all phases of material production and product manufacture, the chemical industry will have an important role in post-attack recovery. For instance, food production is highly dependent on fertilizers, insecticides, preservatives, and various processing chemicals. Chemicals are used directly and indirectly in the production of construction materials as well as in synthetic fabrics. Some manufactured products, such as plastics and paints, use chemicals directly, while others use chemicals indirectly as agents to clean, pickle, or otherwise treat. None of our basic survival materials can be supplied in adequate quantity or satisfactory quality without sources for basic chemicals. In recognition of the importance of the basic chemical industry in the postattack period, the Office of Civil Defense and Stanford Research Institute have funded the present study to examine damage to the industry following nuclear attack.

Various investigations of the vulnerability and/or repair of industries and utilities have been concluded in the past. These included water supply, sewage treatment, electric power systems, steel plants, food processing plants, sugar refineries, petroleum refineries, and industrial plants in general. Although most of these studies were not directed toward the problems of the basic chemical processing industry, they have provided useful guidance and input information.

The concepts and results of the investigation of the repair and reclamation of electric and gas utilities recently completed by URS [1] proved to be the most directly applicable. In fact, the techniques and procedures developed in that study provided the technical basis for the current effort. Other related or complementary studies, covering a broad spectrum of industries (such as petroleum refineries, steel mills, and food processors) and effects (such as blast damage, rapid shutdown, and repair requirements), have been discussed [1].

The research required both a systems approach--supplied by URS--and specialized competency in the field of chemical engineering practices--supplied by Rogers Engineering Co., Inc., of San Francisco. This arrangement proved highly satisfactory and is recommended as a desirable approach for research projects requiring application of both broad concepts and specialized expertise.

Objectives

The Statement of Work is reproduced below.

> The Subcontractor shall provide the personnel and facilities necessary to conduct a research study to develop estimates of damage to industrial facilities from nuclear weapon effects and to develop estimates of manpower and resources to repair and reclaim such facilities. Manufacturing or processing plants representative of those in the SIC* three-digit group 281-Basic Chemicals will be selected on the basis of criteria developed by the Subcontractor. These plans will then be defined in terms of their structures, processes and process equipment, physical layout and other appropriate elements. The definition will include the identification of the degree to which the elements of the plan or processing system are critical to the operation of the facility. For each of these plants and their critical elements, detailed estimates of damage from nuclear weapon effects will be derived primarily on the basis of a 5-MT weapon. Weapon effects will include overpressure, fire, fallout, and others as appropriate. Secondary effects, such as missile and debris effects, will be considered to the extent permitted by the state-of-the-art. Estimates of damage will be restricted to the two conditions of plants under normal operation and shutdown. On the basis of these estimates of damage the requirements will be derived over time for manpower and equipment and other resources for the repair and reclamation of the plants and the restoration of operation. The estimates of damage and repair to individual plant components will be presented in a form such that the findings can be applied to similar components in other plants not considered in this study. To the extent possible the findings developed from the analysis of individual plants will be utilized to characterize plants, in general, of the industry which the specific plants represent.

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* Standard Industrial Classification [2].

From the Statement of Work, a work plan was prepared and the following major objectives were delineated:

1. Identify and characterize the major unit operations or the processes commonly used by the SIC Group 281 industries.

2. For each process identified, analyze the physical damage expected to result from various overpressure ranges from a 5-Mt-range weapon.

3. For each selected process and for each level of damage, prepare repair estimates which include manpower, by skill, and support equipment.

4. Using the damage and repair results for the selected processes, synthesize case studies of selected industries showing (a) probable overall damage at various levels of attack, (b) associated repair requirements, (c) time-phased sequence of repair operations, (d) alternate modes of operation.

Limitations on the Study

The investigation was limited to those industries defined by Standard Industrial Classification (SIC) Group 281; major industries in this group are chlorine-caustic, industrial gases, organic dyes, inorganic pigments, basic organic chemicals, and basic inorganic chemicals.

The range of weapon effects considered included both primary effects (such as air blast, thermal radiation, primary fires, and fallout*) and secondary damage (such as building collapse, secondary fires, utility failure, explosions, and tidal waves). A major portion of the effort was directed at blast effects as these are considered the most important cause of damage [1,3] and predictive methods are relatively well advanced. For those effects where predictive techniques are poorly developed, the analysis considered the possibility or probability of occurrence. While damage estimates were made for the plant in normal operation at the time of attack, if it appeared that the resultant damage would differ markedly with the plant shut down and secured, a second estimate was prepared. Repair estimates were based on restoration of approximately 90 percent of preattack production capability. No consideration was given to the reduced demand for chemical products as a result of the attack.

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* Fallout was not considered a contributor to equipment damage and the possible effects of fallout on susceptible chemical products were not included in this study.

Report Organization

In most cases, the results of the study are reported in the sequence accomplished--that is, from damage estimates to repair estimates to time-phased repair by skill. To facilitate understanding of the material presented, backup and secondary data are presented in Appendixes.

The organization of the report and the relationship of the various sections and appendixes are shown in Figure 1.

Acknowledgments

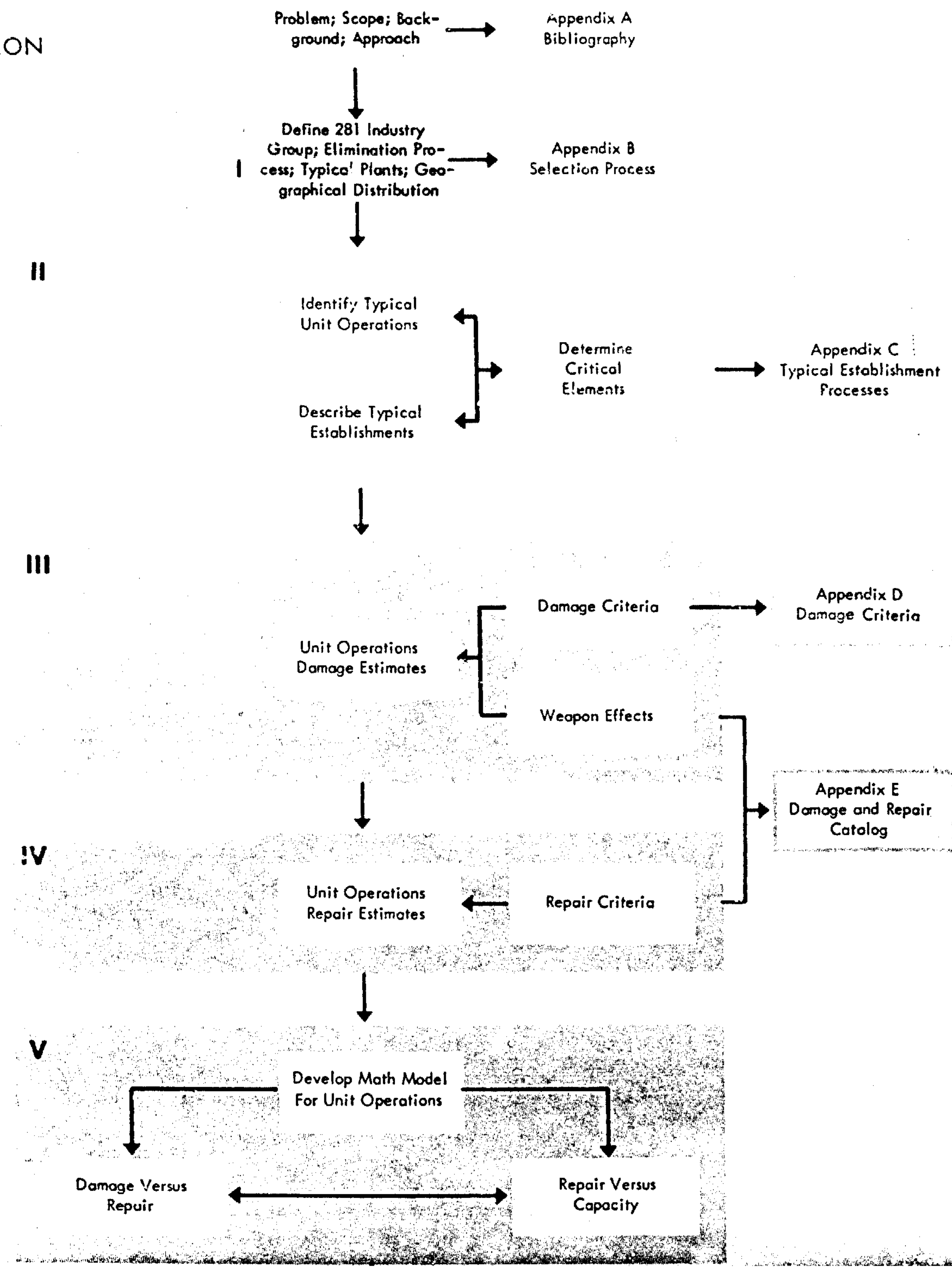
The study was conducted under the guidance of Messrs. R. B. Bothun and R. Rodden of the Civil Defense Technical Office at Stanford Research Institute, who as Technical Monitors provided valuable assistance and direction. Mr. Michael Pachuta, OCD Action Officer, also contributed direction and understanding. The assistance of personnel of Rogers Engineering Co., Inc., is also acknowledged and appreciated. Data provided by the Manufacturing Chemists' Association, Inc., Washington, D.C. also proved helpful in various phases of the study.

The authors are grateful for the assistance of URS personnel who contributed to various sections of this study. Dr. Bernard Gabrielson provided guidance and input for the damage estimates and prepared Appendix A. Miss Lee Saxt assisted in data reduction.

Project manager was W. H. Van Horn; C. R. Foget was principal investigator, and was assisted by M. Staackmann. The entire effort was conducted under the supervision of M. B. Hawkins, Manager of Environmental Systems.

Figure 1

REPORT ORGANIZATION



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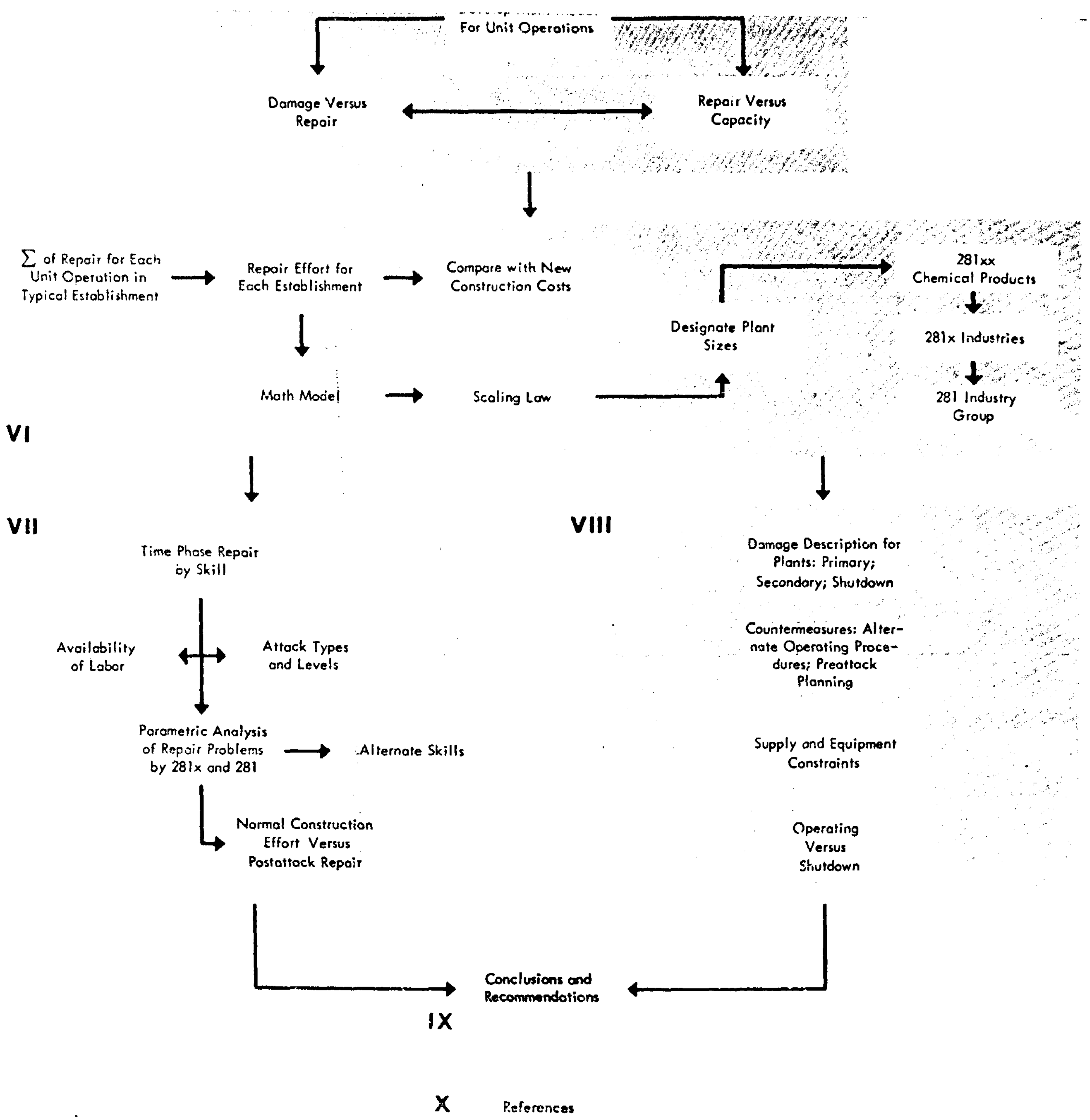
For Unit Operations
Damage Versus Repair
Repair Versus Capacity
∑ of Repair for Each Unit Operation in Typical Establishment
Repair Effort for Each Establishment
Compare with New Construction Costs
Designate Plant Sizes
281xx Chemical Products
281x Industries
281 Industry Group
Math Model
Scaling Law
VI
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Time Phase Repair by Skill
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I

THE BASIC CHEMICAL INDUSTRY

I

THE BASIC CHEMICAL INDUSTRY

The Chemical Industry

The chemical industry is one of the key industries in the United States and includes 14,000 plants in 50 states. When broadly defined, the chemical industry embraces a complex of subindustries. The borders of the industry and of the subindustries are indistinct, for most chemical companies not only manufacture products that fall into a number of subindustry groupings, but produce items classified outside the chemical industry entirely. Conversely, many of the products classified in the chemical industry are manufactured in large quantity by companies listed outside the chemical industry (such as, the petroleum refining industry).

Thus, any system of classification that attempts to separate chemical companies into special segments must be arbitrary to some extent. For reporting purposes, the Bureau of the Census combines establishments producing chemicals and those producing finished chemicals (products) into one major group—Chemicals and Allied Products (SIC 28). SIC subgroup 281 (industrial inorganic and organic chemicals) includes some 1,900 establishments engaged primarily in manufacturing "basic" chemicals that are further processed by other major groups or subgroups to produce end products. The value of shipments for the SIC subgroup 281 in 1965 was $11,438,346,000, which represents approximately 37 percent of the total value of shipments for the SIC 28 group of industries.

Figure 2 illustrates the relationship of the basic chemical subgroup (SIC 281) to the industries (281x*) of the subgroup and to other 28x subgroups. The industries are compared in Figure 2 on the basis of value added by manufacture, adjusted (MVA)[5]. The organic chemicals not elsewhere classified (nec) industry (SIC 2818) represent 48 percent of the total SIC 281 subgroup. Next in relative importance is the inorganic chemicals industry (SIC 2819), representing 27 percent of the total. The remaining SIC 281x industries are a relatively small but vital part of the basic chemical industry group.

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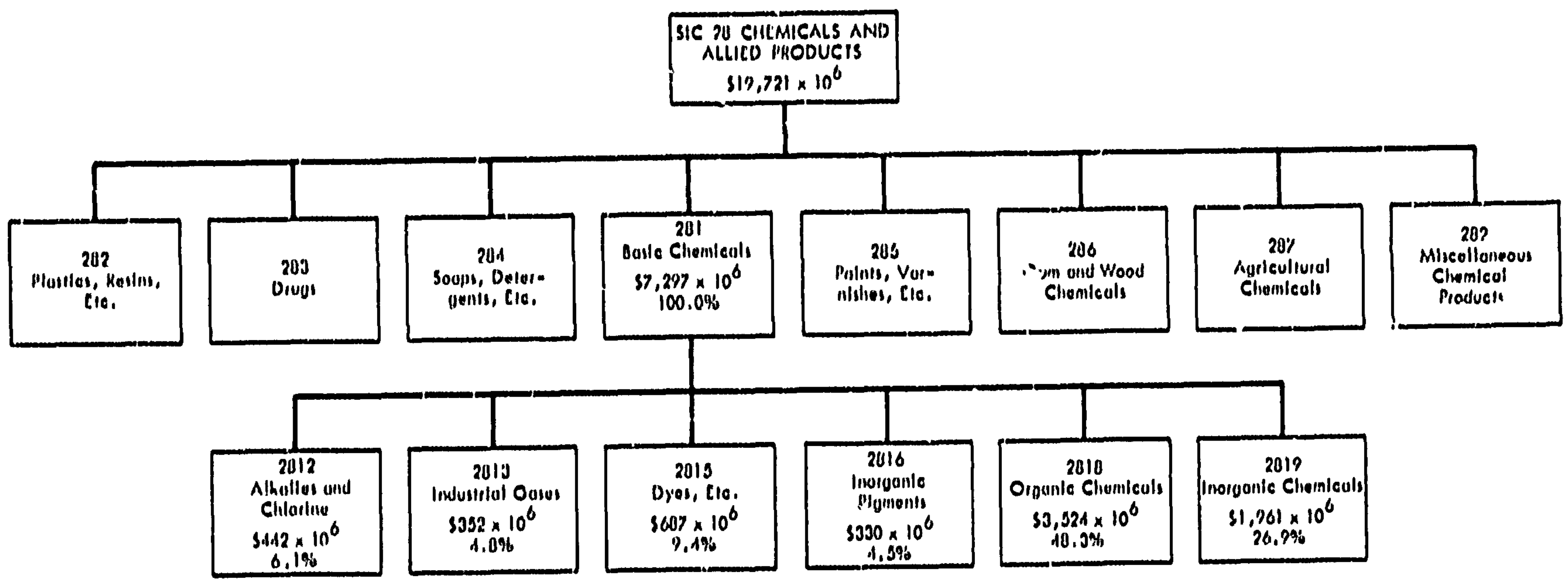
* Hereafter x will be used to indicate undesignated 3-, 4-, or 5-digit SIC subgroups, industries, or products.

Figure 2

THE BASIC CHEMICAL INDUSTRY GROUP (SIC 281)



NOTES: SIC groups from reference 2. Dollar values are for MVA (value added by manufacture, adjusted) for 1965 (reference 4).

Table 1 indicates the degree to which establishments manufacture products classified in more than one industry. (These data are presented in terms of value of shipments made because there is no MVA data for this particular breakdown.) Using these data, the specialization ratio--an index of primary products produced by a given SIC industry--can be calculated. For instance, alkalies and chlorine represent 66 percent of the SIC 2812 industry, and industrial gases 98 percent of the SIC 2813 industry. Secondary products made within the SIC 2812 industry include hydrogen and sodium nitrate, which are classified under the SIC 2813 and 2819 industries, respectively. Another interesting statistic is the value of the primary products made in other industries—for example, 21 percent of the total production of alkalies and chlorine (or $110,538,000) are produced by other industries.

The most modern chemical establishments today endeavor to manufacture their raw materials and produce the finished products. This results in the absence of a clear differentiation among (for example) a petroleum producer, a petrochemical company, and a chemical manufacturer. Another trend is the formation of chemical complexes that are comprised of independent establishments located in the same geographical area with a large volume of intermediate product transfer between establishments. Table 1 indicates this interplant production consumption.

Another definite trend in the chemical industry group (and other industry groups) is the increased use of automation in process control. While automation provides better quality control at lower operational expense, it could prove detrimental in a nuclear attack. Controls and control systems are relatively soft in comparison with most chemical equipment, but are expensive and require extensive labor effort to install. Computer control systems are becoming prevalent [6], particularly in multichemical complexes, and add greater sophistication to the normally complex control systems. Thus, even at relatively low overpressures, the loss of a control system could cause extensive damage to a plant that would not have been damaged by blast effects alone. An illustration of this occurred at a petroleum refinery in Pennsylvania during a four-hour power failure. Although auxillary power was supplied to some instrumentation, the refinery could not restore full production for four days and suffered losses in excess of a quarter of a million dollars [7].

Geographical Distribution of the Basic Chemical Industry Group

The geographic distribution of the 1905 plants in the basic chemical industry group varied. The inorganic chemicals and coal tar products (SIC 2812, 2813, 2815, 2816, and 2819) are widely and fairly evenly distributed throughout the country; however, the organic chemicals (SIC 2818) are concentrated in four states: Texas, Louisiana, California, and West Virginia [8]. Figure 3 indicates that

Table 1

SELECTED CHARACTERISTICS OF 281x INDUSTRIES

SIC Industry Number	Industry Name	Typical Products	Number of Production Employees	Number of Plants	Value of Shipments This Industry (in $1,000) Products	Secondary Products	Specialization Ratio*	Percent of Primary** Product Consumed Interplant	Value of Primary Products Other Industries (in $1,000)
2812	Alkalies and chlorine	Chlorine-caustic, soda ash	13,180	38	115,008	214,180	60%	14	110,538 (21.0%)
2813	Industrial gases	Oxygen, hydrogen, acetylene	5,250	450	310,770	7,778	98	N.A.	18,850 (12.0)
2815	Intermediate coal tar products	Benzene derivatives, synthetic organic dyes and pigments	18,800	177	728,110	327,721	69	23	187,757 (31.7)
2816	Inorganic pigments	Titanium dioxide, chrome pigments	8,135	90	110,532	10,315	91	8	60,820 (12.7)
2818	Organic chemicals n.e.c.	Organic acids, solvents, alcohols, plasticizers, ethylene	57,307	461	3,381,102	1,300,087	[illegible]	55	790,558 (19.1)
2819	Inorganic chemicals, n.e.c.	Sulfuric acid, ammonia, potassium nitrate, sodium metal, bromine	55,415	671	2,417,181	201,135	88	11	778,482 (26.0)

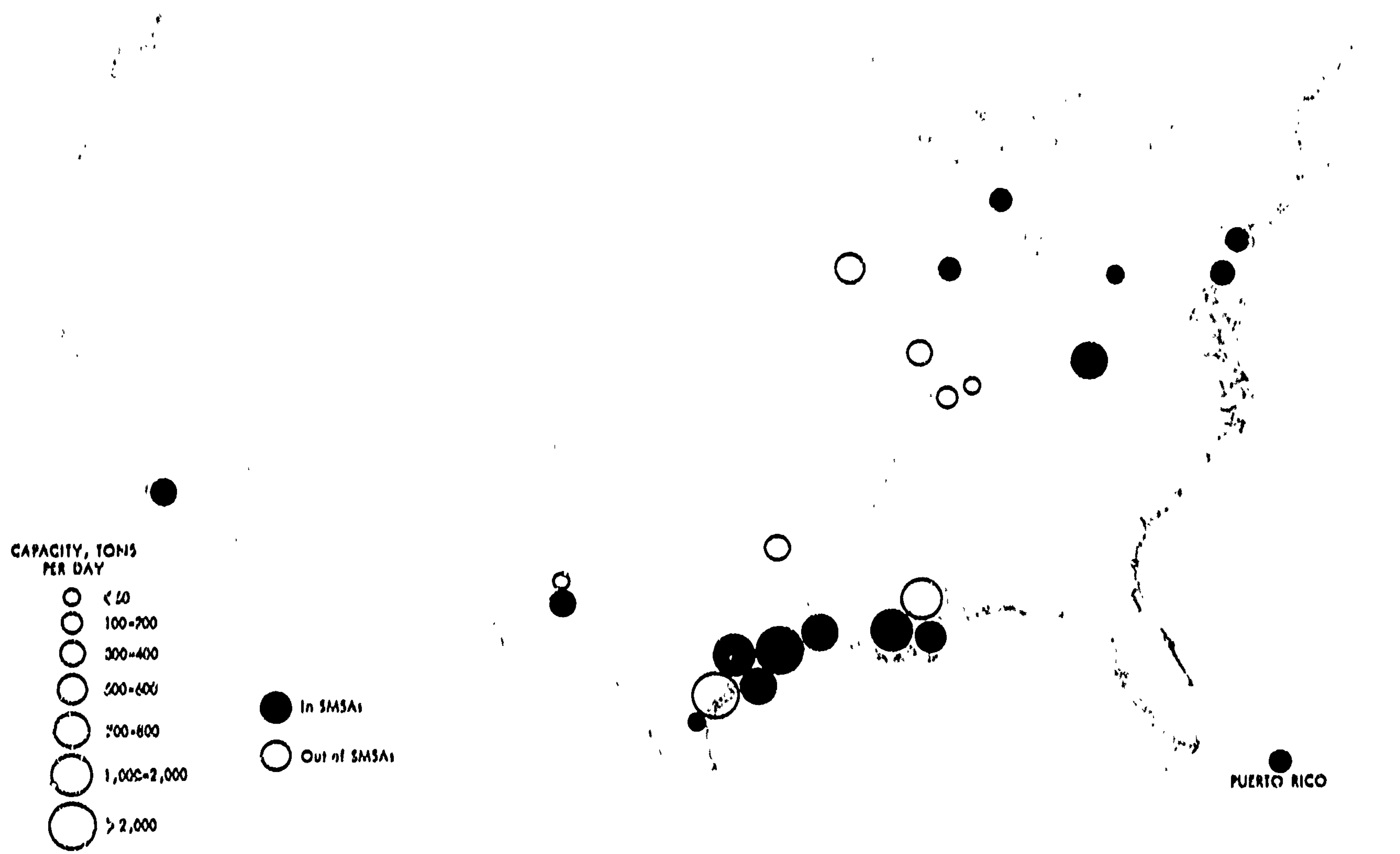
* Specialization ratio $= \dfrac{\text{Value of Primary Product}}{\text{Values of Primary and Secondary Products}} \times 100$

** Estimate based on most important primary products

Source: From Ref. 5, MC(63)-28A, Tables 5A and 6A.

Figure 3

CAPACITY AND LOCATION OF ETHYLENE PLANTS IN THE U.S.



approximately 54 percent of the ethylene production capability is located in SMSAs and over 80 percent is concentrated along the Texas-Louisiana Gulf Coast [9]. A few dozen well-placed nuclear weapons would incapacitate ethylene production plants. Since ethylene is a basic chemical, this would jeopardize the production of other chemicals.

The extent of damage that the basic chemical industry could expect to receive in the event of a nuclear attack can be related to the proximity of the chemical industry to population areas or Standard Metropolitan Statistical Areas (SMSAs). Figure 4 shows the percentage distribution (based on 1965 production) of each industry in the 281 industry group and the 281x industries located in and out of SMSAs. As Figure 4 indicates, three industries—2812, 2813, and 2815—have over 80 percent of their production capability located inside SMSAs, while the other three industries have at least 60 percent or more of their production capability so located. The entire 281 industry group has over 70 percent of its production capability located in SMSAs. This indicates that less than 30 percent of the industry group could expect to remain unscathed following a nuclear attack concentrated on the SMSAs.

A major trend of the basic chemical industry group, particularly the petrochemical industry (2818), has been to the interrelated chemical plant or multichemical complex. In this type of an operation, as many as 10 or 12 separate chemicals are manufactured within one plant, with many of the chemicals utilized internally to manufacture other chemicals which are the final end products. One result of the multichemical complex trend has been a tendency for different chemical complexes to become interconnected by pipelines and through interplant transfer to sell various chemicals necessary for another plant's processes. Although this procedure has provided an economy of scale that has contributed to the growth of the petrochemical industry, it could prove disadvantageous if a plant supplying the necessary feed stock is shutdown, thus causing a "domino" effect whereby all dependent plants might have to shutdown [9]. These interplant connections probably will have a great effect on the postattack recovery of the chemical industry since the damage to or destruction of one chemical plant might incapacitate several other plants 40 or 50 miles distant. An example of relatively long distance interconnections is the Orange-Beaumont-Port Arthur, Texas, area that has interconnections with plants almost 60 miles away in the Lake Charles, Louisiana, area [10]. While this was a problem beyond the scope of this study, it would be useful to perform an in-depth study of a large multichemical plant complex such as that located in Giesmar, Louisiana, or the Houston, Texas, area [11] and more accurately ascertain the effects a nuclear weapon attack would have on an interconnected chemical complex.

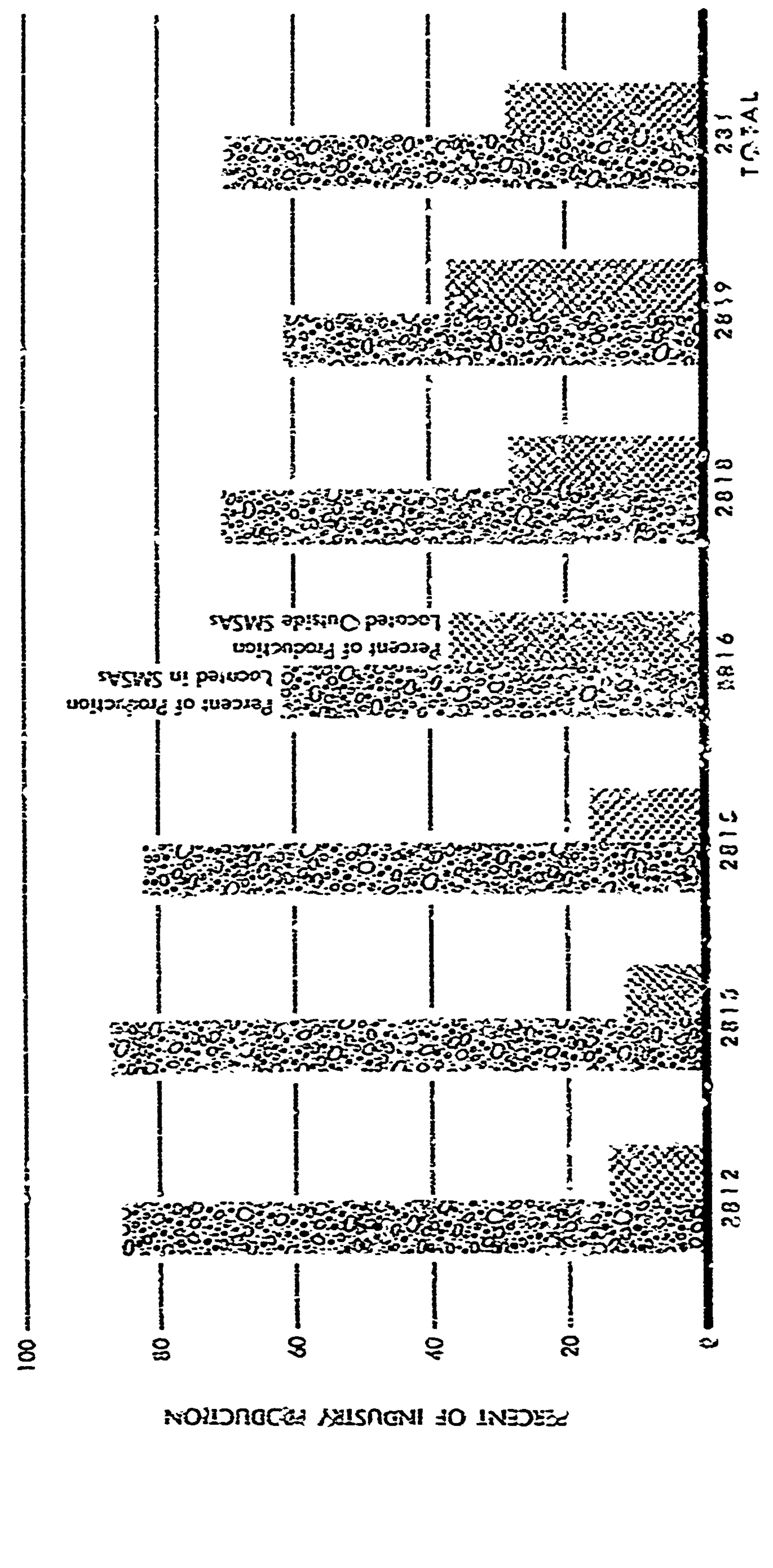


Figure 4
DISTRIBUTION OF SIC 281x INDUSTRY GROUPS

Criteria for Selection of Representative Industries and Establishments

The individual process lines used in basic chemical industries included in the Standard Industrial Classification Group 281 are too numerous to analyze in depth. A selection process whereby a limited number of establishments were isolated by a set of criteria designed for optimum satisfaction of the research objectives was performed at two levels. The first level examined the six major industry headings (2812, 2813, 2815, 2816, 2818, and 2819) within the group to decide whether any of the major headings could be eliminated from detailed study; the second level examined all of the chemical products (281xx and lower) listed under each of the qualifying major headings. For each of the selected representative industries, a typical establishment (producing the selected chemical products) was designated as representative of that particular major industry heading.

The criteria used in selection of the representative industries and establishments are as follows:

- The industry/establishment shall have importance in the postattack period.
- The industry/establishment shall represent a considerable volume (weight) and dollar value.
- The industry/establishment shall produce chemicals with wide application in a variety of uses and over a wide geographical area.
- The industry/establishment shall utilize processing equipment and techniques representative of those used throughout the basic chemical industry group.
- The industry/establishment shall produce chemicals not readily available through alternate sources.

Using the above criteria for industry, alkalies and chlorine (2812), industrial gases (2813), organic chemicals (2818), and inorganic chemicals (2819) were retained for detailed study. The other industries (2815 and 2816) were studied further, but only in a gross manner. Table 2 summarizes the results of the selection process; further details are included in Appendix B.

Next, products that would be representative of each of the 281x industries retained were selected (using the same criteria) and typical establishments manufacturing these products were designated. The details of the selection process are given in Appendix B and the results are summarized in Table 3.

Table 2

SIC 281x INDUSTRIES SELECTED FOR DETAILED STUDY

SIC Industry	Postattack Importance	Production Volume	Number of Essential Uses	Processes and Equipment	Alternate Sources
2812*	High	Moderate	Many	Unique	Few
2813*	High	Moderate	Many	Typical	Few
2815	Moderate	Moderate	Some	Typical	Many
2816	Low	Moderate	Limited	Unique	Few
2818*	High	High	Many	Typical	Some
2819*	High	High	Many	Typical	Few

* Industries retained for detailed study.

Table 3

REPRESENTATIVE ESTABLISHMENTS
SELECTED FOR DETAILED STUDY

SIC Industry	SIC Product Code Number	Product	Product/Industry Ratio*
2812	28121	Chlorine	0.61
	28123	Sodium hydroxide	
2813	28134 54	Oxygen	0.51
	28134 43	Nitrogen	
	28134 15	Argon	
2818	28182 11	Ethylene	0.022
2819	28193	Sulfuric acid	0.062 } 0.107
2819	28191 50	Ammonium nitrate	0.045

* A ratio of the MVA for the chemical products indicated over the total MVA for industry which the products represent.

As Table 3 indicates, the establishments chosen to represent the 2812 and 2813 industries manufacture products that represent more than 1/2 of the total MVA (0.61 for SIC 2812 and 0.51 for SIC 2813); the choices are obvious. For the SIC 2818 industry, the choice of an establishment producing ethylene--representing only 2.2 percent of the total industry MVA--is less certain although it is the largest single chemical produced in the 2818 industry. However, it was determined that an ethylene plant represents physically, if not in terms of process, most organic plants. Accordingly, using the ethylene plant as an example of the very large industry was deemed valid. The 2819 industry is represented by two establishments--one producing sulfuric acid (a representative liquid chemical) and another producing ammonium nitrate (a representative bulk solid chemical); these two products represent approximately 11 percent of the total 2819 industry MVA.

II

TYPICAL ESTABLISHMENTS AND PROCESS EQUIPMENT

II

TYPICAL ESTABLISHMENTS AND PROCESS EQUIPMENT

The basic chemical industries comprise chemical establishments that utilize various chemical process equipment. This chemical process equipment can be considered the working modules characterizing a particular chemical plant. Thus, the first step in determining probable damage and subsequent repair effort was to identify the chemical process equipment. Two previous studies [3,12] presented methods by which manufacturing equipment (including chemical process equipment) could be classified. In the first study, Sachs and Bickley of IDA [3] classified equipment as: general purpose, special to industry, or unique to the product, with subdivisions of light and heavy, and regular and precision. The second study by the National Planning Association [12] presented a more detailed classification under three broad headings: specialized equipment, common equipment, and auxiliary facility modules. As these studies examined the entire manufacturing industry, their classification systems had to encompass the entire range of manufacturing equipment. Since this study investigated one industry group, a classification system specific to chemical equipment was devised in conjunction with the Rogers Engineering Company.

Process Equipment and Auxiliary Equipment

Rogers Engineering provided URS with a list of the standard equipment used in the basic chemical industry. From this list, URS and Rogers selected 37 items of chemical equipment and 9 auxiliary equipment that would be representative of the total 281 industry group. These modules provided the basis for a catalog from which various types of chemical establishments could be built hypothetically.

Table 4 lists the chemical equipment and auxiliary equipment included in the catalog and represents for each typical plant the specific equipment modules that make up that plant.

Figure 5 illustrates the layout of a typical chemical establishment and the relationship of various components of chemical equipment. The pressure vessels, cooling tower, storage tanks, heat exchangers, control house, and pipe rack are typical of the chemical industry. Appendix C contains more detailed information on the equipment and the processes of the five typical establishments.

Table 4

CHEMICAL EQUIPMENT AND AUXILIARY EQUIPMENT

	Equipment Used in Specific Establishment				
	2812 Caustic - Chlorine	2813 Air Liquifaction	2818 Ethylene	2819 Ammonium Nitrate	2815 Sulfuric Acid
Columns and Pressure Vessels					
C-1 Distillation Column		x	x		x
C-2 Liquid/Liquid Extraction Column					
C-3 Packed Column					x
C-4 Pressure Vessel - Horizontal Cylindrical		x	x	x	
C-5 Pressure Vessel - Vertical Cylindrical		x	x	x	
C-6 Liquid Phase Reactor with Mixer				x	
C-7 Fluidized Bed Vertical Reactor					
Storage Tanks					
C-8 Atmospheric Storage	x			x	x
C-9 Spherical Storage		x			
C-10 Solids Storage				x	
C-11 Open Storage Tanks	x				
Exchangers					
C-12 Horizontal Shell and Tube	x	x	x	x	x
C-13 Vertical Shell and Tube		x			
C-14 Multiple Effects Evaporator	x				
C-15 Cooling Tower Induced Draft	x	x	x	x	x
Fired Heaters					
C-16 Box Type - Floor Fired			x		
C-17 Horizontal Fired Rotary Kiln				x	x
Pumps and Drivers					
C-18 Centrifugal Pump	x	x	x	x	x
C-19 Electric Motor Drives	x	x	x	x	x
C-20 Steam Turbine Drives					x
C-21 Blower					x
Vacuum Equipment					
C-22 Steam Jet Ejector				x	

(continued)

Table 4 (Continued)

	Equipment Used in Specific Establishment				
	2812 Caustic - Chlorine	2813 Air Liquifaction	2818 Ethylene	2819 Ammonium Nitrate	2819 Sulfuric Acid
Compressors					
C-23 Reciprocating Compressor		x			
C-24 Centrifugal Compressor	x	x	x		
Special Equipment					
C-25 Barometric Condensor	x				
C-26 Bell and Spigot Drying Tower	x				
C-27 Centrifuges	x				
C-28 Electrolytic Diaphram Cell	x				
C-29 Electrolytic Mercury Cell					
C-30 Rotary Vacuum Filter	x				
C-31 Screw Conveyor				x	
C-32 Thickener or Clarifier	x			x	
C-33 Acid Coolers					x
Package Units					
C-34 Refrigeration Units		x			
C-35 Regenerative Liquid or Gas Drying Systems		x			
Instruments					
C-36 Control Cubicles	x	x	x	x	x
Piping					
C-37 Pipe Racks	x	x	x	x	x
Gas System					
A-1 Gas Regulator	x	x	x	x	x
A-2 Gas Meter	x	x	x	x	x
Electric System					
A-3 10 MVA Transformer	x	x	x	x	x
A-4 Electric Switchgear	x	x	x	x	x
A-5 Rectifier	x				
Water and Sewer System					
A-6 Vertical Sand Filter	x	x	x	x	x
A-7 Elevated Water Tank	x	x	x	x	x
A-8 Package Boiler Unit	x			x	
Building					
A-9 Prefab Buildings	x	x	x	x	x

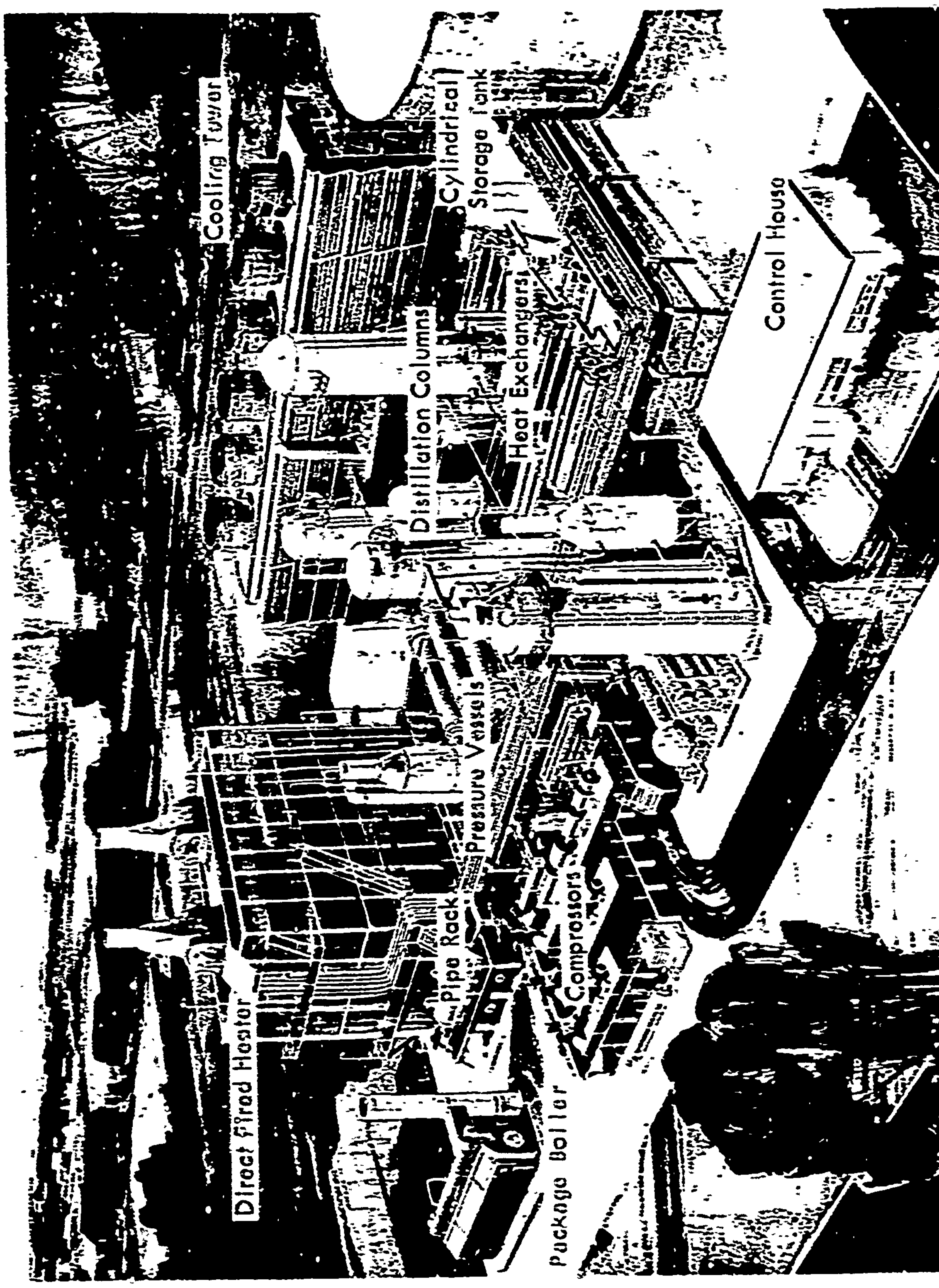


Figure 5
A TYPICAL CHEMICAL ESTABLISHMENT SHOWING IMPORTANT COMPONENTS

Critical Elements

One of the goals of this study was to ascertain the critical elements in the typical chemical manufacturing establishments. The ascertainment of the relative importance of various chemical equipment components to an overall chemical process is necessary since the postattack repair effort would probably place major emphasis on getting the chemical plant back "on the line." To accomplish this in the most expeditious manner, components contributing a fraction of efficiency undoubtedly would be bypassed. In a previous study on the gas and electric utilities [1], the equipment components of the two utilities were almost always used in exactly the same manner in each plant; this permitted a fairly rigid definition of their criticality. In the chemical industry, however, an item of chemical equipment might be critical in one plant but not in another (a filter might be absolutely necessary in one process but of minor importance in another). As this restriction precluded the assignment of a criticality rating to chemical equipment listed in the catalog, the equipment was rated for its criticality on a plant-by-plant basis.

Accordingly, the functional contribution of each element was carefully examined, and criticality was rated according to the following classifications:

CRITICAL C	Loss of element would result in a loss of <u>more</u> than 10 percent of the design capacity. The cause of this reduction in capacity might be due to operational limitations or a degradation of the system's safety or reliability.
SEMICRITICAL SC	Operation without element would result in a loss of <u>less</u> than 10 percent of design capacity. The safety or reliability of the system might be degraded, but not seriously. Conversion of the system to operate without this element would require a significant expenditure of manpower and/or materials.
NONCRITICAL NC	Operation without element, would result in a loss of <u>less</u> than 10 percent of design capacity. The safety or reliability of the system might be degraded, but not seriously. Conversion of the system to operate without this element would not require a significant expenditure of manpower and/or materials.

Figures C-1 through C-5 of Appendix C depict the ratings of each chemical component.

III

DAMAGE ESTIMATES

III

DAMAGE ESTIMATES

The 46 equipment modules in the chemical equipment catalog were examined to determine the extent and nature of damage they would receive as a result of nuclear attack. The purpose of these damage estimates was to establish a quantitative relationship between given levels of damage and the overpressure at which such damage would occur. This information was subsequently combined with information relating damage to the repair effort required for restoration and resulted in establishing a relationship between overpressure and repair requirements. Damage was assumed to be produced by a 5-mt low air burst with all overpressures in the Mach region. Although a rigorous analysis of other weapon yields was not pursued, the results of the damage estimations are believed to be applicable for weapon yields in the low megaton range (1.0 - 10.0 mt). The major difference in blast phenomena for weapons of different yields (besides distance) is the duration of the positive phase of the blast wave. Although this duration changes with the overpressure level (it is the longest at low overpressures), over the weapon yields mentioned it is of sufficient duration to equal or exceed the natural period of the equipment structures investigated in this study. For example, a distillation column 88 ft high by 4 ft diameter has a period of 2.6 secs. At 9 psi, the column would overturn due to anchor bolt failure. At this overpressure level, the duration of the blast wave is 2.75 and 6.3 secs for yields of 1 and 10 mt, respectively. Therefore, the duration exceeds the period of the structure and the wave can be considered a static loading force. For weapons of lower yields, certain structures will have periods that now are greater than the blast wave duration values. Under these conditions, the assumption that the wave acts as a static loading force no longer applies and damage to such structures will be less than predicted by large weapons at the same overpressure levels.

Weapon Effects and Secondary Damage

The primary nuclear weapon effects considered in analyzing damage to the chemical equipment components were the diffraction and drag phases of the blast wave and the thermal pulse. Secondary damage was mainly assessed in a qualitative manner and was mainly attributed to missiles generated by the diffraction and drag phases of the blast. Other secondary damage investigated briefly was due mainly to the nature of the chemical processes themselves (such as a liquid oxygen spill from a ruptured storage tank). Appropriate references [13, 14, 15] were used where applicable. All damage effects were related to the overpressure

level at which they occurred. Three weapon effects--electromagnetic pulse (EMP), direct-induced ground shock, and air-induced ground shock--were not considered with respect to their effects on individual chemical equipment components but possible implications are presented.

Electromagnetic pulse (EMP) fields are reported (in the open literature) to be of sufficient intensity to produce appreciable degradation of communications, power, and computer systems even outside the range of extensive blast damage. Although the complexity of these systems and the many possible interactions preclude the development of detailed vulnerability assessment procedures [16], some implications can be made. If the EMP effects cause a power failure, the subsequent unscheduled shut-down of the plant could cause serious damage, including secondary fires and explosions [11]. If the EMP effects disrupt communications within the plant or erase the magnetic memory of the computer in a highly automated plant, the plant might experience an unscheduled shut-down with similar disasterous consequences. A prolonged power outage also would effectively disrupt the capability of the computer.

Direct-induced ground shock can cause damage to underground lines and components of chemical plants, the degree of damage falling off rapidly with distance from ground zero. It is expected that underground components will receive significant damage only within the zone of plastic soil movement. Since this zone is relatively small and would simultaneously be subjected to extremely high overpressure and thermal levels, the direct-induced ground shock is felt to be of minor significance. A special case occurs for chemical plants located in the vicinity of a body of water in which the nuclear detonation occurs [27]. Under these conditions, coupling effects could produce significant structural damage in ranges where the air blast effects would produce no such damage. However, additional research is necessary to establish the extent of the problems likely to be created by direct-induced ground shock.

Air-induced ground shock is expected to cause virtually no damage to underground chemical plant components at surface overpressure levels below 15 or 25 psi. Above this level, damage is expected to occur, with severity increasing with overpressure. It was concluded [1] that the present proficiency is not sufficiently advanced to allow even approximate quantitative prediction of damage resulting from given overpressure levels.

Damage Estimation

The estimation of the probable damage to the various equipment modules considered in this study involved assessing the module to determine the most likely failure modes and, using standard engineering formulas, calculating the overpressure level at which the element would fail. Since generalized damage

estimations of equipment modules are desired, standard design criteria (for example, 100-mph wind force) with appropriate safety factors were used to arrive at a structural resistance to blast effects for a given module. From this resistance, the failure-overpressure was calculated. Realizing that calculated failure levels would not be accurate for all types of any given module or even for two identical types, we derived a mathematical method of assessing the probability of failure for a given loading condition based on observed structural failure response. These probability-of-failure factors were applied to the calculated failure levels and an overpressure range given which corresponded with failure probabilities of 1 percent, 50 percent, and 99 percent. Appendix D presents the rationale and a more detailed discussion of the procedures used.

Two factors affect the severity of damage at any given overpressure levels: the directional orientation of the element to the blast wave front and the proximity of the element to other components or structures. In the directional orientation of a chemical equipment component, the worst-case orientation was assumed (that orientation producing the greatest damage from blast effects). The proximity of components to other components or structures also affects the severity of damage resulting from both missiles and reflected overpressures. The significance of missile damage is discussed below. Reflected overpressure was not examined in detail due to a lack of specific information regarding equipment location relative to possible blast-reflecting surfaces.

Results

The validity of the damage estimates that were prepared for this study would be in the range of a "study estimate" as defined by the American Association of Cost Engineers [18]. This means that the damage estimates would have a probable error of no more than plus or minus 30 percent, based on the stated overpressure. If the damage estimates are to be applied to equipment that is either considerably larger or considerably smaller than the standards used for this study, the probable error would be greater.

Damage estimates were prepared for chemical equipment in both an operating and a shut-down condition. In many cases, there was little or no difference in the equipment damage predicted for the two modes. However, secondary hazards could exist if the chemicals contained inside the equipment were allowed to leak or spill. The major exception to this tenet involved storage tanks and process vessels--empty tanks or vessels became more susceptible to damage at lower overpressures.

Appendix E describes the damage for each chemical equipment and auxiliary module. The damage predictions are based on actual computations involving response of the materials making up the modules to the various weapon effects.

For each damage description, the cause of the damage is noted (diffraction, drag, missile, or a combination of these three) with the overpressure level at which the failure would occur for an estimated probability of 1 percent, 50 percent, or 99 percent failure. As an example of the use of these charts, at 6.6 psi, there would be a 50 percent probability that a distillation column (C-1) would have external pipe severed at the ground connections due to deflection of the column.

The findings for overpressure and dynamic pressure evaluated in detail were:

- Overpressure (diffraction phase) was found to be a major cause of damage to buildings, storage tanks, cooling towers, electrolytic cells, and controls. In other instances, it was a contributing cause of damage with other weapon effects.

- Dynamic pressure was found to be the major cause of damage to certain exposed equipment components. These components were columns, process and pressure vessels, heat exchangers, pumps and drivers, compressors, most of the special equipment, package units, and piping.

The findings for those weapon effects assessed only on a qualitative basis were:

- Missiles were found to contribute significantly to the damage of nearly all equipment components. Those elements located inside buildings or in relatively built-up areas were damaged primarily by missiles generated by overpressure effects. Elements located outdoors in less built-up areas received damage from missiles propelled by the drag effects of the dynamic pressure.

- Thermal pulse was found to cause varying but relatively insignificant damage to the equipment components. The most significant effect of the thermal pulse was its initiation of primary ignitions and its contribution to secondary fires, the effects of which could not be covered in detail in this study.

A wide range of damage response versus overpressure existed for the equipment components in the study; severe damage levels, for instance, ranged from 5 psi for a cooling tower to 24 psi for a horizontal heat exchanger. For presentation purposes here and in preparing the repair estimates for the next section, damage conditions considered are for the 50 percent failure probability and the corresponding overpressures. Generally, the vulnerability of the chemical equipment modules to damage can be delineated in three broad classifications: soft, where severe damage* is experienced below 5 psi; medium, where severe

* Severe damage as used here refers to severe distortion of the equipment frame and/or displacement of the equipment off its mountings.

damage is experienced between 5 and 10 psi; and hard, where severe damage occurs at greater than 10 psi. The list below shows examples of chemical equipment modules in these classifications.

Soft, 2-5 psi

Controls	Diaphram cells
Cooling towers	Storage tanks (except spherical)
Fired furnaces	Control buildings

Medium, 5-10 psi

Pipe racks	Screw conveyors
Blowers	Columns
Mercury cells	Multiple effects evaporator
Rotary vacuum filters	Package boilers

Hard, >10 psi

Heat exchangers	Steam and electric drivers
Pressure vessels	Centrifuges
Compressors	Spherical storage tanks
Pumps	

IV

REPAIR ESTIMATES

IV

REPAIR ESTIMATES

Repair estimates were prepared for the 46 equipment modules at each indicated level of damage. The Rogers Engineering Company assembled a panel of experienced engineers from their staff plus a representative from URS and for each equipment module at each damage level, evaluated the effort in man-days to complete the repair, the time needed for the repair, the specific labor skills required, special construction equipment needed, and resources necessary for repair (supplies and spare parts). This evaluation was performed by means of engineering judgment and standard construction estimating techniques. The various equipment modules were assigned for estimation to individuals on the panel according to their expertise. Each engineer audited the estimates to achieve a group consensus.

Repair Criteria

In a postattack environment, there would be many limitations on the repair of any physical facility—whether a chemical plant, an electric utility, or a school house. Undoubtedly there would be shortages of the necessary skilled labor, equipment, and supplies. However, as it was beyond the scope of this study to take such diverse factors into account, the following criteria were used for deriving the repair estimates for each component:

- All repairs would be performed by skilled repair personnel using the equipment, supplies, and facilities normally available under preattack conditions, unless otherwise noted.

- The repaired system would be virtually identical to the original (preattack) system from the standpoints of design, performance capabilities, operational requirements, reliability, safety, and longevity.

The following basic assumptions were made for all repair estimates:

- No unusual environmental conditions (inclement weather, frozen soil, flooding, high groundwater table, fallout radiation, fires, or remote or inaccessible location) are present to interfere with the repairs.

- Travel time to and from repair sites is not included.

- Time is allowed for the field testing of each repaired element but not for testing the entire system following repair.

- The values given for repair effort do not include the time spent by supervisory personnel above the level of "foreman."

Results

Appendix E presents the results of the repair analysis in tabular form. Both damage and repair estimates are keyed to overpressure, with other weapon effects cited specifically as applicable. The validity of the repair estimates were in the same range as that of the damage estimates (a "study estimate") and should be accurate to within plus or minus 30 percent. A further refinement of the repair estimates reflecting different sizes of the same piece of equipment is discussed in Section V.

In general, the repair effort required to restore the chemical equipment components to an operating mode reflected both the complexity of the piece of equipment and its vulnerability to blast damage. To illustrate this point: a direct fired heater is a large complex piece of chemical equipment and is also structurally soft (it suffers severe damage at less than 5 psi); consequently, it required the largest repair effort (400 man-days). A 2,500 hp centrifical compressor, also a large complex item of equipment but structurally very hard, required only 47 man-days of repair effort at its severe damage level. For the most part, the chemical equipment modules in the hard category required less repair effort than the equipment modules in the soft and medium categories.* In addition, the type of repair was much different since most of the equipment classified as hard suffered little or no internal damage and required only realignment or resetting on foundations. Equipment modules in the medium and soft category required the greatest repair effort since the majority of this equipment would experience both external and internal damage at the severe damage levels. While the type of repair was varied, generally it required some form of complete rebuilding.

As an example of the use of the repair estimates (using the example given above), the repair of a distillation column at 6-1/2 psi would require 35 man-days of repair effort; take 4 days to accomplish; require a crane, oxyacetylene cutting torches, rigging gear, and electrical welding machines; pipes, miscellaneous wrenches, and gaskets; and a repair crew comprising of 4 riggers, 2 equipment operators, 1 millwright, 2 pipe fitters, 1 ironworker, and 2 certified welders.

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* Or, as a corollary, most "hard" components, because they are often designed to operate under the stresses of very high pressure, are less complex than "soft" components and hence less subject to extensive repair requirements.

V

MATHEMATICAL MODELS FOR REPAIR ESTIMATES

V

MATHEMATICAL MODELS FOR REPAIR ESTIMATES

In a previous study [1], a mathematical model was developed that used an exponential function relating repair effort to overpressure. The purpose of the mathematical model was to take the data for the repair of individual equipment components (such as that presented in Appendix E) and express them in a more compact and facile form. The model served another purpose by allowing interpolation between data points so that a repair effort could be expressed for every overpressure level. As mentioned in Section III, all weapon effects considered (overpressure, dynamic pressure, missiles, and thermal pulse) have been related to one effect: overpressure. Hence, even though overpressure is the index used, all effects that contribute to damage to a given component are implicit in this index.

This mathematical model (with some revision) satisfactorily related the damage at various levels of overpressure to the estimated repair effort for each of the 46 chemical equipment components studied. The mathematical function used to express this relationship is:

$$R = L\left[1 - e^{-k(p-x)^{y}}\right] \tag{1}$$

where

R = repair effort (man-days)
L = maximum repair effort (man-days)
p = overpressure (psi)
x = lowest overpressure (50 percent probability estimate) at which damage is observed, psi
k = empirical constant for a given equipment module
y = empirical constant for a given equipment module

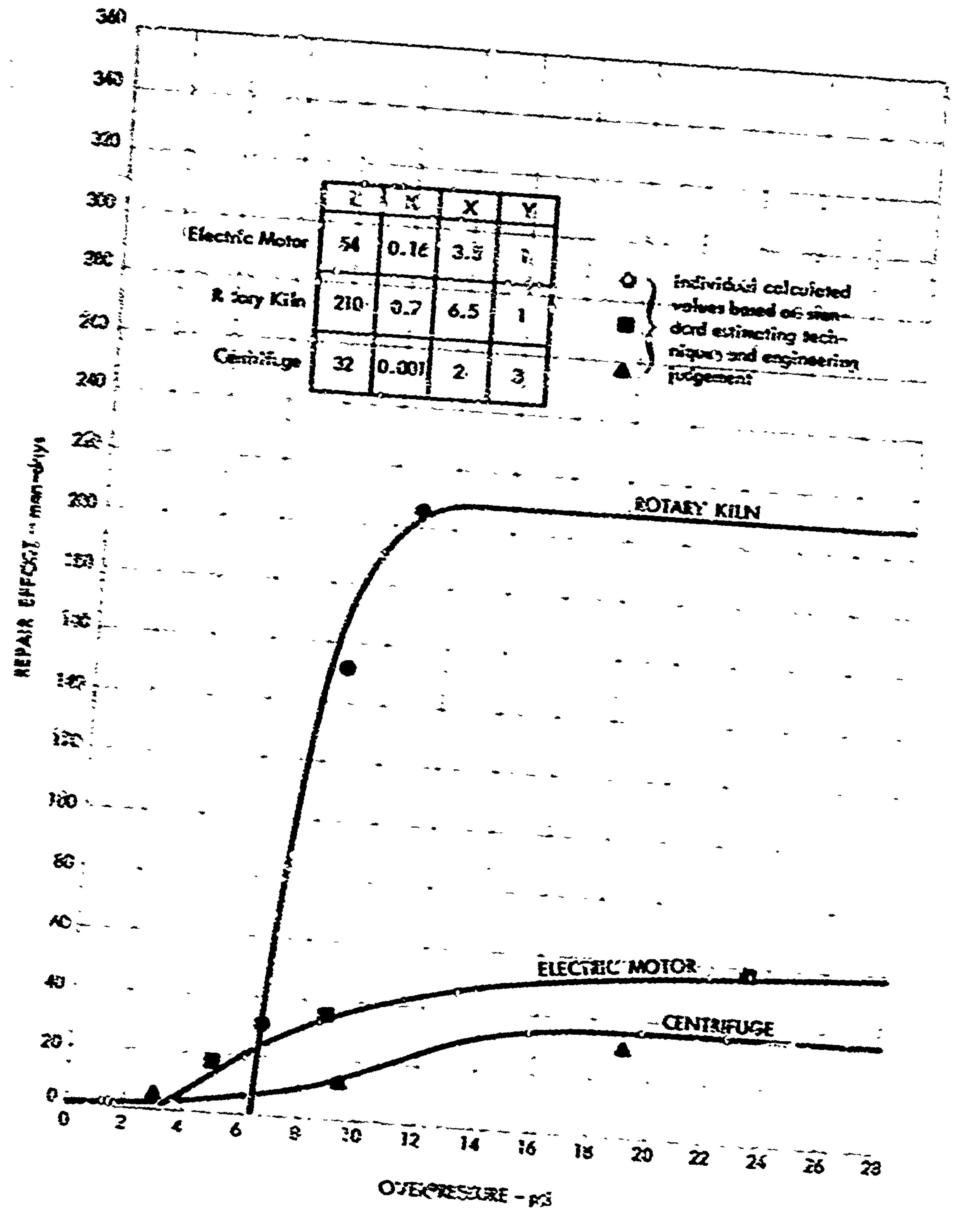
Empirical constants, to give an expression that best fit the data for repair estimates of each component, were found by successive iterations.

Results

Generally, the mathematical functions express the damage/repair relationship of most of the chemical equipment components in a highly satisfactory manner. Figure 6 shows three typical examples (an electric motor, a rotary kiln, and a centrifuge with their corresponding mathematical parameters) of the curves

Figure 4

REPAIR EFFORT VERSUS OVERPRESSURE LEVELS FOR THREE CHEMICAL EQUIPMENT COMPONENTS



obtained for the chemical equipment components. These curves are representative of the accuracy of the curve fits to the data points obtained by the mathematical model. As was found with the previous study [1], deviations of the model from the calculated values do occur, usually for low repair efforts (therefore of less importance). However, "study estimate" validity (accuracy to within plus or minus 30 percent) is the premise employed.

Repair Versus Capacity Model

The size or capacity of a typical equipment component varies widely throughout the chemical industry (a distillation column may be as short as 20 ft or as tall as 300 ft) and since the effort required to repair a chemical equipment component in most cases varies with size of the component, this factor had to be taken into account. Another mathematical expression was developed to allow scaling of the repair effort and the scaling factor—different for each piece of chemical equipment—allowed the scaling of repair effort to match the size (or capacity) of a given chemical equipment component. This flexibility permitted a more precise estimate of repair effort for each typical plant. In addition, the scaling factor was a time-saving device since it permitted an easily determined repair estimation for any component not of standard size.

Scaling Model

The expression for the scaling factor was derived empirically from the repair effort data supplied by Rogers Engineering. For each chemical equipment component, the determination was made on the type of repair performed at each damage level, and whether the repair would change with size (welding a seam on a large or small tank) or remain the same despite a size variation (replacing instrumentation gauges). The repair estimates for three sizes of the same piece of equipment were then graphically depicted and the following equation was derived to represent the graphical results:

$$S_f = m\left(\frac{C}{C_o}\right) + b \tag{2}$$

where

S_f scaling factor for a given chemical equipment component

m - empirical constant for a given equipment component

C = capacity or size of equipment component being investigated

C_o capacity or size of equipment component standard

b empirical constant for a given equipment component

In use, the scaling factor is multiplied by the repair effort derived from the mathematical model (eq. 1) for the standard equipment component, to give eq. 3, which represents the relationship between damage and repair for an equipment component of any given size:

$$R_s = L\left(1 - e^{-k(p-x)^y}\right)\left[m\left(\frac{C}{C_o} + b\right)\right] \quad (3)$$

where R_s = repair effort for any size component (man-days).

Results

For each of the 46 equipment modules, Table 5 lists the 7 parameters that were used (L, k, x, y, m, b, C_o) to define the repair effort for that equipment component in the mathematical model. The scaling parameters (m and b) varied at different overpressure levels for several of the chemical components and are indicated in the table. Table 5 indicates several variations of scaling that have to be taken into account. In some cases, a piece of chemical equipment will not vary in size but is truly a module (a modular equipment component would be manufactured in one size only) and more of the same size module are added when an increase in capacity is desired. This type of equipment is identified by the term "modular" in the m and b columns. In another case, the repair effort for a given piece of equipment varies directly with a certain standard dimension (C_o) and in this case m = 1 and b = 0. Finally, in some instances, the repair effort remains constant for any size of a given equipment component and is so designated in Table 5 where the m = 0, b = 1 and C_o is left blank (the size of the equipment is not relevant).

The technical literature [19-24] contains many articles concerning the scaling of chemical equipment by size or capacity. However, the literature reviewed uses either the initial cost or installed cost in dollars of the chemical equipment versus size or capacity as the units of measure. The scaling method used for this study is different from the methods usually found in the literature* and is not directly comparable to the results that these methods give. The reason is that the equipment scaling method in this report is strictly concerned with the repair effort for different sizes of chemical equipment; whereas the standard, cost-versus-size methods are concerned with the overall cost of purchasing and installing a chemical equipment component and include many other cost factors besides the actual installation labor (such as shipping, material cost, and manufacturing labor).

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* The classical method is the exponential capacity-adjustment technique that uses a constant exponent value of 0.6 for most types of processes. An example of this method is given in Reference 21.

Table 5

MATHEMATICAL MODEL PARAMETERS FOR EQUIPMENT REPAIR

	L	k	x	y	m	b	C_o
C-1 Distillation Column	280	0.003	6	4			1100 ft^3
psi ≤ 8*					1.1	-0.08	1100 ft^3
psi > 8					0.84	0.13	1100 ft^3
C-2 Liquid/Liquid Extraction Column	340	0.004	6	4			1100 ft^3
psi ≤ 8					1.1	-0.08	1100 ft^3
psi > 8					0.84	0.13	1100 ft^3
C-3 Packed Column	220	0.005	5	4			1100 ft^3
					0.63	0.30	1100 ft^3
C-4 Pressure Vessel - Horizontal Cylindrical	31	0.37	12	2	0	1	
C-5 Pressure Vessel - Vertical Cylindrical	30	1.1	12	1	0	1	
C-6 Liquid Phase Reactor w/(Full) Mixer	36	0.015	1.9	2	1	0	6'φ** x 8' (226 ft^3)
(Empty)	32	0.55	1.9	1	1	0	6'φ** x 8' (226 ft^3)
C-7 Fluidized Bed Vertical Reactor							
psi ≤ 4	24	0.3	2.1	1	1.4	0.30	6'φ x 30'
psi > 4					1.2	0.20	

* The values indicated apply for all overpressure levels unless otherwise indicated.

** φ represents diameter.

(continued)

Table 5 (continued)

	L	k	x	y	m	b	C_o
C-8 Atmospheric Storage Tanks							
(Full)	170	2.3	0.3	1	1	0	50' diam. x 20'
(Empty)	180	2.7	0.5	1	1	0	50' diam. x 20'
C-9 Spherical Storage Tanks	200	0.005	7	3	0.90	0.18	80' (diam.)
C-10 Solids Storage Tanks	170	0.000001	3.5	5.7	2	0	21'φ x 72'
C-11 Open Storage Tanks	61	0.05	4	2	1	0	10φ
C-12 Horizontal Shell & Tube Exchangers							
(single)	15	0.35	12	1	0	1	
(stacked)	30	0.8	7	2	0	1	
C-13 Vertical Shell & Tube Exchanger	15	0.4	13	1	0	1	
C-14 Multiple Effects Evaporator	210	0.0005	4	5	0.50	0.50	3 effects 25' x 15'
C-15 Cooling Tower, Induced Draft	88	0.1	0	2	Modular	4 cells	20' x 20' x 15'φ
C-16 Box Type Floor-Fired Heater	370	1.5	0.9	1	1	0	45,000 ft^3
C-17 Horizontal Fired Rotary Kiln							
(w/Brick)	210	0.7	0.5	1	1	0	10'φ x 75'
(w/o Brick)	103	0.5	0	1	1	0	10'φ x 75'

(continued)

Table 5 (continued)

	L	k	x	y	m	b	C_o
C-18 Centrifugal Pump	0	0.7	12.5	1	1	0	10'φ x 75'
C-19 Electric Motor Drives	54	0.16	3.5	1			
psi ≤ 5					0.88	0.10	1000 hp
psi > 5					0.74	0.25	1000 hp
C-20 Steam Turbine Drives	18	0.007	8	2.5			
psi < 14					0.64	0.47	25 hp
psi ≥ 14					0.80	0.25	
C-21 Blower	17	0.45	4	1	1	0	150 hp
C-22 Steam Jet Ejector	10	0.008	10	3	6	1	
C-23 Reciprocating Compressor	33	0.098	2	2	0.59	0.40	1000 hp
C-24 Centrifugal Compressor	51	0.11	2.9	1			
psi ≤ 8					0.39	0.61	2500 hp
psi > 8					0.51	0.45	2500 hp
C-25 Barometric Condenser							
psi ≤ 3	26	1.1	1	1	0.32	0.67	5'φ x 8'
psi > 3					0.24	0.76	
C-26 Bell & Spigot Drying Tower	46	0.8	3	1	1	0	5'φ x 20' (4 stages)

(continued)

Table 5 (continued)

	L	k	x	y	m	b	C_o
C-27 Centrifuges	32	0.001	2	3			30 hp
psi ≤ 14					0.31	0.70	
psi > 14					0.21	0.80	
C-28 Electrolytic Diaphram Cell	15	0.6	2	1	Modular		6' x 6' x 6'
C-29 Electrolytic Mercury Cell	35	0.2	1	1	Modular		40' x 4' x 0.5'
C-30 Rotary Vacuum Filter	27	0.22	0.1	1			6' drum
psi < 4					0.91	0.10	
psi ≥ 4					0.70	0.30	
C-31 Screw Conveyor	14	0.3	2.5	1	Modular		20' section
C-32 Thickener or Clarifier	54	0.7	2	1			
psi ≤ 3					1.50	-0.50	50' (diam.)
psi = 4					1.00	0	50' (diam.)
psi ≥ 5					0.80	0.17	50' (diam.)
C-33 Acid Cooler	23	0.5	4.5	2	Modular		1250 ft^2
C-34 Refrigeration Units	24	0.2	1.4	1	0	1	
C-35 Regenerative Liquid or Gas Dryer	10	0.005	1	3	0	1	
C-36 Control Cubicles	20	1	1	1	Modular		4' x 4' x 7.5'
C-37 Pipe Racks	82	0.8	4.5	1.7	0.83	0.16	20' wide x 20' lg.

(continued)

Table 5 (concluded)

	L	k	x	y	m	b	C_o
A-1 Gas Regulator	2.1	0.7	5	1	Modular		Industrial Size
A-2 Gas Motor	2.1	0.9	1.5	1	Modular		Industrial Size
A-3 10 MVA Transformer	130	0.0007	1	4	Modular		
A-4 Electric Switchgear	65	0.4	4	1.3	Modular		Sized for 10 MVA
A-5 Rectifier	100	1	2.3	1	Modular		20' x 10' x 10'
A-6 Vertical Sand Filter	32	0.22	2.5	1	0	1	
A-7 Elevated Water Tank							
(full)	27	1.4	3	1	1	0	5'φ x 8'
(empty)	22	1.3	1.2	1	1	0	
A-8 Package Boiler Unit	120	0.08	1.5	2			
psi ≤ 3					0.45	0.54	7×10^7 Btu/hr
psi = 4					0.59	0.42	7×10^7 Btu/hr
psi ≥ 5					0.71	0.28	7×10^7 Btu/hr
A-9 Prefab Buildings	64	0.5	1	1	1	0	5600 ft^2 (floor area)

To find the repair effort for a 1,000 hp centrifugal compressor at 12 psi, for example, use the parameters given for a centrifugal compressor (C-24) in Table 5 and substitute them in eq. 3 as follows:

$L = 51$ $m = 0.51$
$k = 0.11$ $b = 0.45$
$x = 2.9$ $C_o = 2,500$ hp
$y = 1$ $C = 1,000$ hp
$p = 12$

$$R_{12\ psi} = 51\left[1-e^{-0.11(12-2.9)^{1}}\right]\left[0.51\frac{1000}{2500} + 0.45\right]$$

$$= 21 \text{ man-days of repair effort}$$

VI

REPAIR ESTIMATES FOR TYPICAL ESTABLISHMENTS AND INDUSTRIES

VI

REPAIR ESTIMATES FOR TYPICAL ESTABLISHMENTS AND INDUSTRIES

Procedure

The SIC 281 industry group was differentiated successively from industry group to industry, to product, to establishment manufacturing the product, and, ultimately, to basic process equipment of the establishments. At this lowest common denominator—the process equipment common to all establishments and industries within SIC 281 group—detailed damage and repair analyses were made.

Using a mathematical model derived in Section V for each item of process equipment, it is possible to estimate the repair effort (50 percent failure probability) versus overpressure for each of the typical establishments by assembling the process equipment required for each and adding up the repair estimates for the constituent process equipment. The total repair effort then is estimated for all the manufacturing capability involved in the total production of the chemical products. This is done by comparing the typical establishment's annual production of its product with the total annual production of that product. This ratio and the repair estimate for the typical establishment are used to derive the repair estimate for the total product manufacture. (This estimate includes factors necessary to account for "atypical" establishments, that is, establishments with production capabilities, products, and process equipment different from the typical.) Ultimately, repair estimates for the 281x industries and 281 industry group can be obtained in this same manner. Figure 7 shows this integration process. At each of the levels the repair estimates for items in the typical unit are summed and repair estimates for the atypical units are either estimated or otherwise compensated for. For example, at the establishment level (five or more digit SIC code), we studied a 400-ton per day chlorine-caustic plant that produced only chlorine and caustic by the Hooker process. (Appendix C gives an analysis and report of the process equipment; Appendix E indicates corresponding damage and repair estimates.) Other plants with differing production capability were not examined in detail. We did not study a chlorine plant using DeNora cells, nor did we investigate byproducts such as soda ash. Hence, we have had to calculate the repair estimate for total chlorine-caustic product by including considerations for atypical as well as typical establishments. These estimates were of a gross nature and often no more than a simple extrapolation. Important exceptions will be noted. The use of such approximations does decrease the reliability of the repair estimates increasingly as the integration of the industries progresses, but the results, even at the 3-digit SIC level, are believed adequate for general planning purposes.

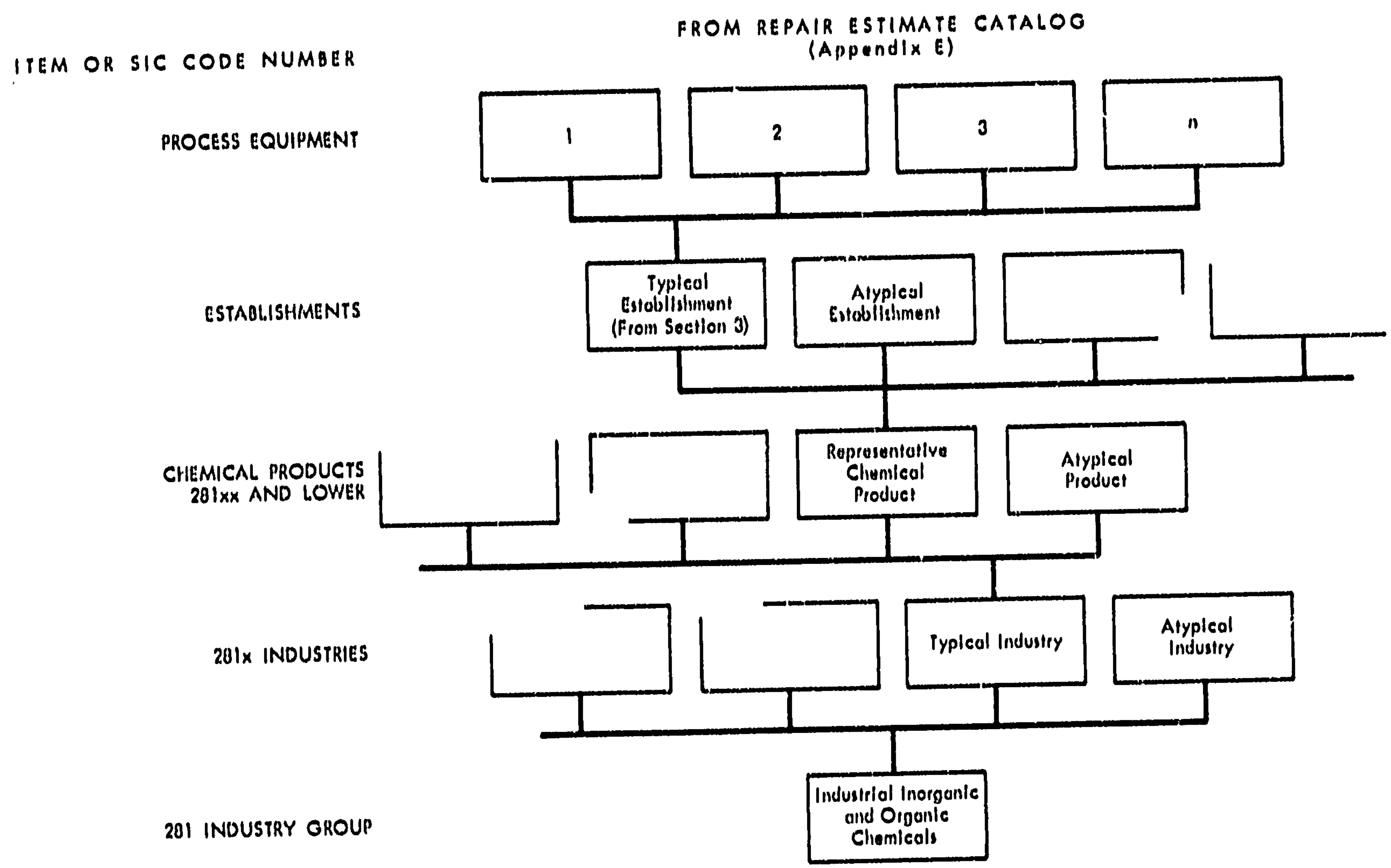


Figure 7

PROGRESSION FROM REPAIR ESTIMATES FOR PROCESS EQUIPMENT TO TOTAL INDUSTRY GROUP REPAIR ESTIMATE

Repair Estimates for Typical Establishments

Repair estimates for a typical establishment are obtained through the summation of the repair estimates for all chemical processing equipment in that particular plant. Though simple in concept, the actual practice is complicated because of network-type components (such as control wiring and miscellaneous piping). The network-type components were usually accounted for by the use of an appropriate rule-of-thumb. It was generally assumed that miscellaneous conduits and piping not carried on pipe racks (component C-37) accounted for an additional piping quantity equivalent to 20 percent of the piping carried on pipe racks. However, variations compensating for individual plant characteristics were used when necessary.

Figure 8 presents the results of this summation process for the five establishments considered (Figures C-1 to C-5 show plant layouts). It was found most convenient to obtain initial results by summation at several overpressure levels as this provided a basis for derivation of a mathematical expression for each curve thus generated. The mathematical expressions derived for these curves were all reduced to a common equation which is identical to Equation 1 except the repair effort parameters and empirical constants are now applicable for the individual establishments rather than the equipment components. Table 6 indicates the establishment parameters used in deriving these mathematical expressions.

Table 6

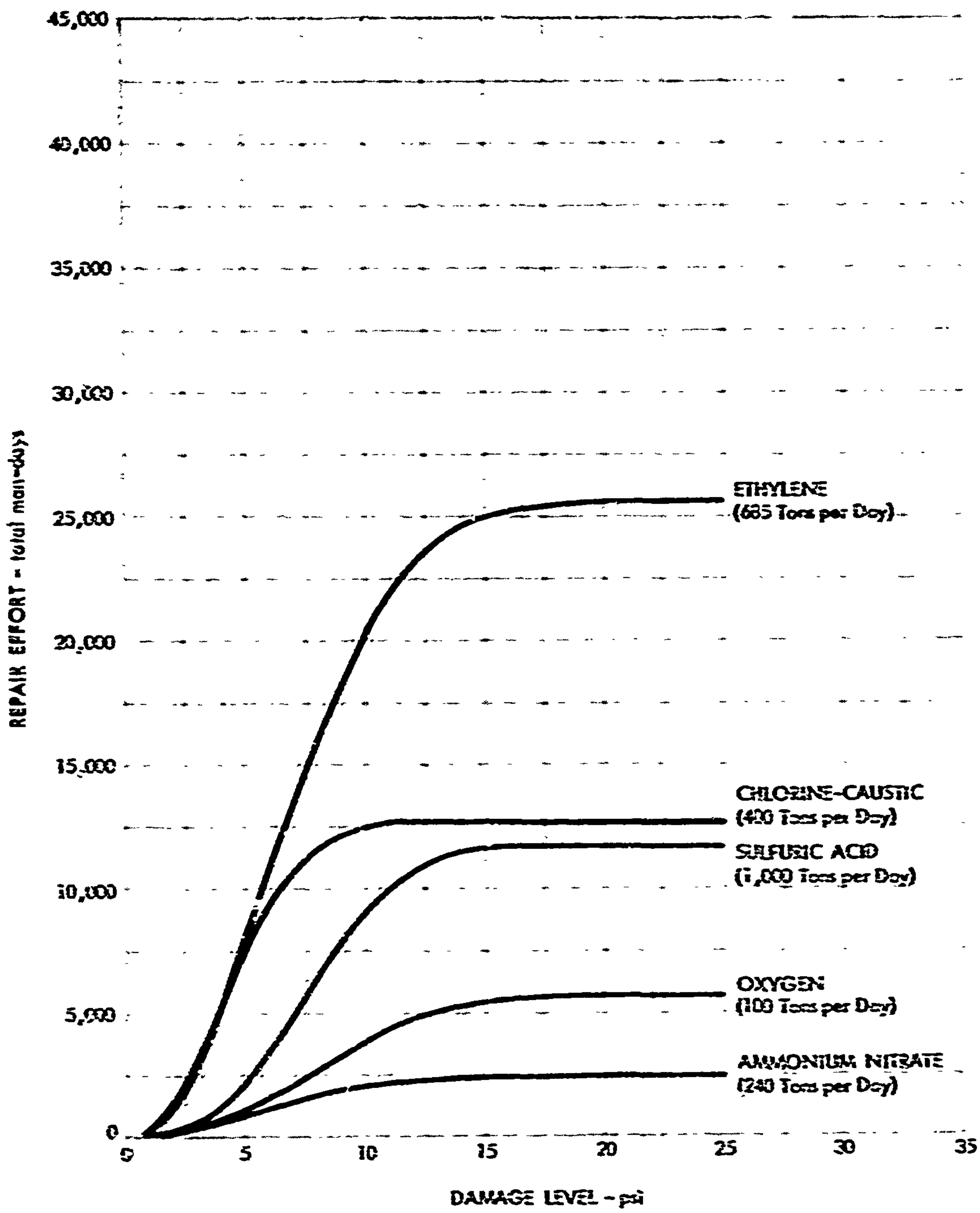
MATHEMATICAL MODEL PARAMETERS
FOR TYPICAL ESTABLISHMENTS

Establishment	Size (tons/day)	Parameters L	k	x	y
Chlorine/caustic	400	12,600	0.043	0.5	2.0
Oxygen	100	5,510	0.005	0.5	2.4
Ethylene	685	25,600	0.01	0.1	2.2
Sulfuric acid	1,000	11,575	0.002	0.2	2.9
Ammonium nitrate	240	2,260	0.02	0.5	2.0

In Figure 8, damage level is expressed as overpressure (in psi), and repair effort is expressed in total man-days for the typical establishments with the indicated production capacities. The use of normalized repair effort, expressed in man-days per ton per day of production capacity, is not permissible since repair effort scales differ with size for the different establishments.

Figure 8

REPAIR EFFORT AS A FUNCTION OF DAMAGE LEVEL FOR FIVE TYPICAL ESTABLISHMENTS



In order to examine the scaling of repair effort with changes in plant size, a second damage versus repair iteration was performed on two additional plants for each of the five typical establishments, using capacities different from the typical. These results were depicted graphically for each establishment type and eq. (4) was then derived to represent the graphical results:*

$$R' = R'_o\left(\frac{C'}{C'_o}\right)^n \tag{4}$$

where

R'_o = Repair effort for the typical establishment

C'_o = Size or capacity of the typical establishment

C' = Size or capacity of the establishment being investigated

R' = Repair effort for the establishment being investigated

n = Scaling factor

Table 7 indicates the scaling factors for each chemical establishment studied.

Table 7

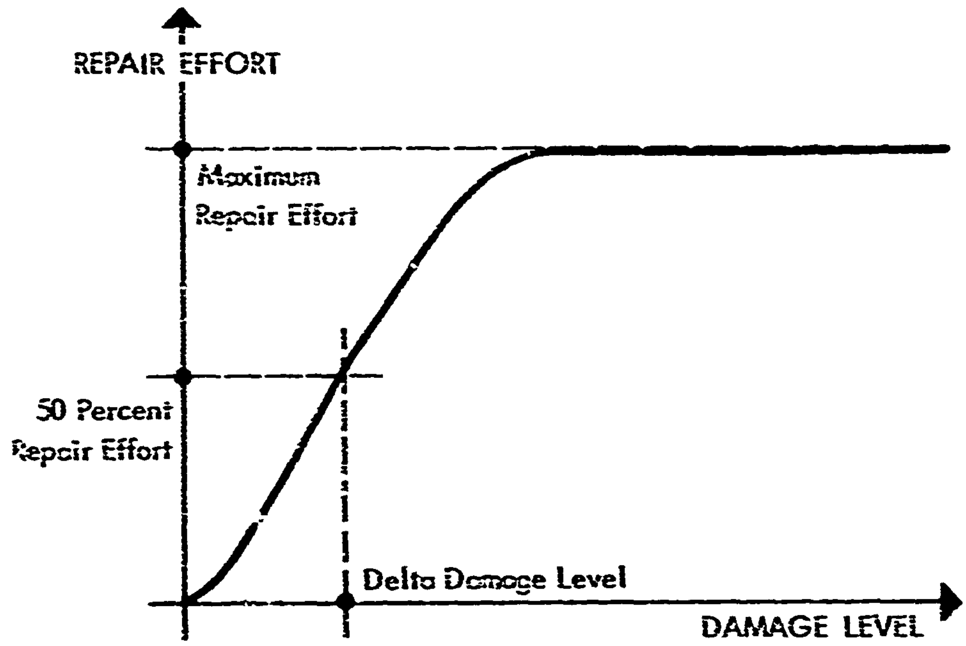
SCALING FACTORS FOR REPAIR EFFORT VERSUS SIZE FOR THE TYPICAL ESTABLISHMENTS

Typical Establishment	Capacity (C'_o, tons/day)	Repair Effort** (man-days)	Scaling Factor (n)
Chlorine/caustic	200 (chlorine)	7,300	0.71
Oxygen	100	3,200	0.61
Ethylene	685	12,800	0.71
Ammonium Nitrate	240	1,000	0.55
Sulfuric Acid	1,000	6,200	0.48

* The form of this equation is similar to that one used in the chemical industry for scaling estimated plant costs; an example of the use of this equation for scaling is given in Reference 18.

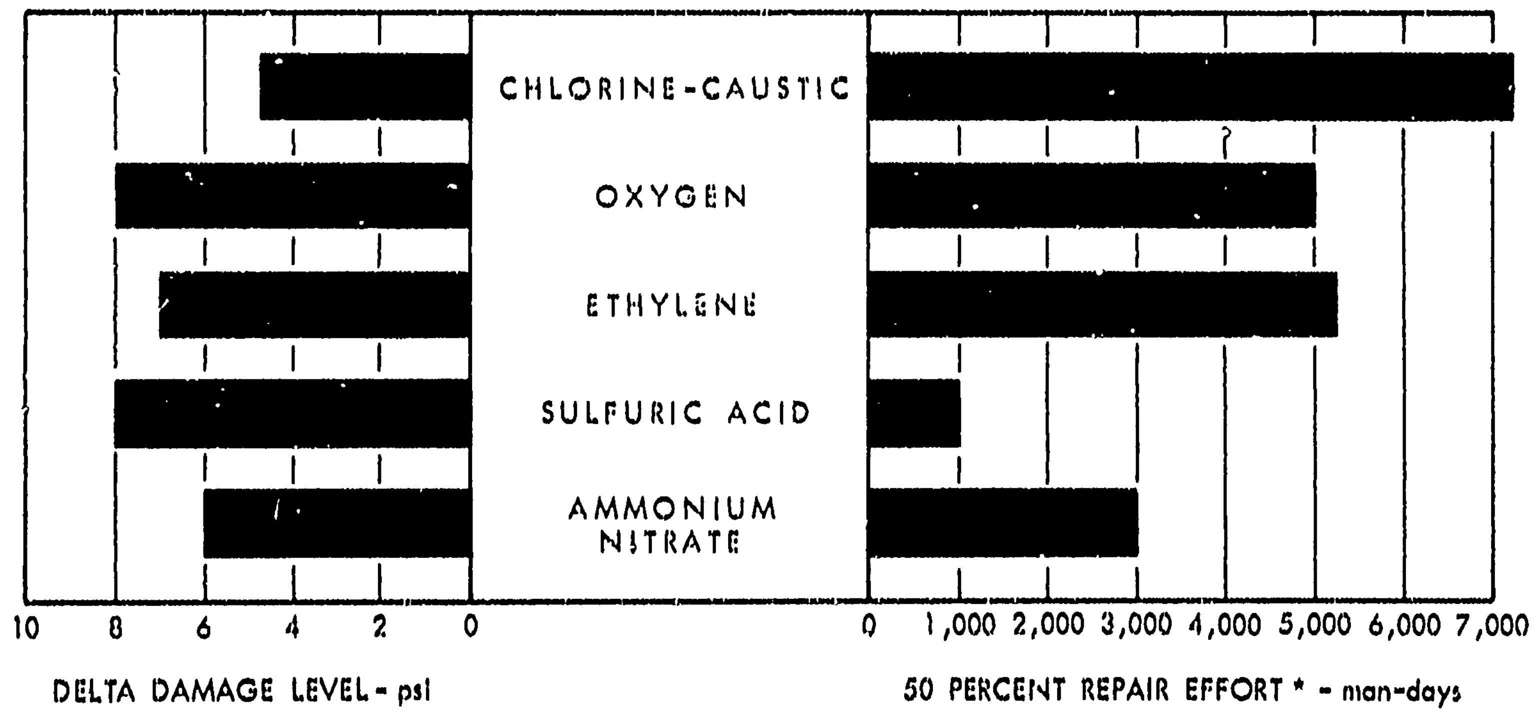
** The repair effort chosen for examination here corresponds to 50 percent of the maximum repair effort for each of the typical establishments.

Two useful indices can now be derived from Figure 8 and Table 7--delta damage level and 50 percent repair effort. These indices are being employed so that the various establishments can be compared on a common basis. The delta damage level corresponds most closely with the moderate damage category commonly used in nuclear weapon effects terminology. The 50 percent repair effort and delta damage level indices are shown on an example curve below:*



For any particular typical establishment, the delta damage level was not found to vary significantly with changes in plant size. For subsequent damage estimations the delta damage level was rounded off to the nearest integral psi. The 50 percent repair effort index depends on plant size, and comparisons of this index should be made using establishments having the same production capacity. These two indices are displayed in Figure 9; there is no correlation between delta damage level and 50 percent repair effort. For example, the chlorine/caustic plant is the most vulnerable (i.e., damage occurs at the lowest overpressure level) and it is also one of the most "expensive" to repair. On the other hand, the sulfuric acid plant is relatively "hard" and repair effort is relatively low.

* For example, the maximum repair effort for an ethylene plant is 25,600 man-days; the 50 percent repair effort is then 25,600/2 = 12,800, which corresponds to a delta damage level of 7.0 psi.



* The 50 percent repair effort index here is for establishments all with capacities of 200 tons per day. Over the total range of from 100 to 1,000 tons per day capacity, the relative ranking of the various establishments remains the same even though differences between them become greater with larger capacities.

Figure 9

DELTA DAMAGE LEVEL AND FIFTY PERCENT REPAIR EFFORT FOR TYPICAL ESTABLISHMENTS

Despite the lack of correlation on a plant-by-plant basis, the relationship between delta damage level and 50 percent repair effort appears fairly consistent, within a given SIC 281x industry, as is discussed in Section VII. The two typical SIC 2819 establishments (ammonium nitrate and sulfuric acid) have relatively low repair efforts, which indicates the simplicity of their manufacturing processes in comparison with those of the other three establishments.

Repair Estimates for the 281xx Chemical Products

A proper representation of different chemical plant sizes was required to extrapolate the findings of the typical establishment analysis to the total production of the chemical products being represented. Since the basic repair versus damage data were tied to the typical establishment capacities, the repair effort had to be scaled to plants of different sizes; the scaling factors derived are given in Table 7.

A stepwise procedure was used to extrapolate the results of the typical establishment repair analysis to the 281xx chemical product. The first step entailed selecting a spectrum of representative plant sizes. Then, using the scaling factors of Table 7, the total repair effort for this mixture of establishments was calculated. By comparing the production of this assortment of plants with the total annual production of the chemical product, it was possible to calculate the repair effort required for the total production of the chemicals involved.

Repair Estimates for the 281x Industries

The extrapolation of the repair efforts for the 281xx chemical products to the 281x industries was performed using the 1965 annual production of each industry as the basis for the integration procedure. For the 2812 industry, a simple ratio of the annual production of the chlorine/caustic industry to the total 2812 industry annual production was used to extrapolate the repair estimates. A similar procedure for the 2813 industry used the production of oxygen, nitrogen, and argon relative to the total 2813 industry production.

A somewhat different procedure was employed in ascertaining the repair effort for the 2818 industry. While ethylene is the largest volume chemical produced in the 2818 industry, it also utilizes one of the simpliest processes of the industry in manufacturing its product. Therefore, to take into account the increased complexity of the rest of the 2818 industry, the repair effort for the ethylene plant was doubled, and the ratio of its production to 2818 industry production was used to arrive at the final repair effort for the total industry. The factor of 2 was derived by comparing the price per ton of ethylene to

the average price per ton of the total production of all chemicals of the 2818 industry.

Extrapolation of the typical plant results to the 2819 industry was somewhat more complicated. Since both liquid and solid chemicals are produced in the 2819 industry, the sulfuric acid industry was used to represent the liquid chemicals portion of the industry (except for ammonia) and ammonium nitrate was used to represent the solid chemicals portion. The ammonia industry is unique and represents a sizable segment of the 2819 industry (11 percent); therefore, it was given special consideration. The ammonia process, which is classified in the 2819 industry, is more representative of a petrochemical process, and therefore the ethylene plant was used to represent it. These three typical industries were then extrapolated to the 2819 industry by using their respective repair efforts and the ratio of the liquid chemicals, solid chemicals, and ammonia production to the total 2819 industry production.

Results of the integration process for the 281x industries are shown in Figure 10 for the 2812, 2813, 2818, and 2819 industries. The relationship between repair effort and overpressure levels was found to fit the mathematical model expressed in eq. 4; the curves shown in Figure 10 (with their corresponding parameters) are based on this mathematical expression.

Repair Estimates for the 281 Industry Group

Two of the six industries (2815 and 2816) that make up the 281 industry group were not analyzed in detail in this study, since they are a part of the 281 industry; however, approximations as to their repair efforts were required. It was assumed that the repair effort for these two industries would be proportional to the total repair effort of the other four industries that were investigated. The extrapolation procedure was similar to that used previously. The ratios of the annual production (in tons) of the 2815 and 2816 industries to that of the total 281 industry group were multiplied by the summation of the repair effort for the other four industries to obtain the total repair efforts for both the 2815 and 2816 industries—equivalent to 7 percent of the total for the other four industries.

Table 8 shows for the six 281 industries, the repair effort in man-days for each industry per annual unit of output, and the repair effort in man-days for each industry as a function of the 1965 MVA of each industry. The results for the four industries (from Figure 10) were then summed over the 1 to 25 psi range of overpressures (plus the fixed 7 percent effort to account for the 2815 and 2816 industries) to arrive at the total repair efforts for the 281 industry group as a function of overpressure level (Figure 11). In these calculations, it was assumed that 90 percent of the preattack production capability is restored by the repair effort; this allows for the noncritical components that could account for 10 percent of production capacity (see Section II). The mathematical model (eq. 4) was the basis for the curve in Figure 11.

Figure 10

REPAIR EFFORT VERSUS DAMAGE LEVEL FOR THE 281x INDUSTRY GROUPS STUDIED

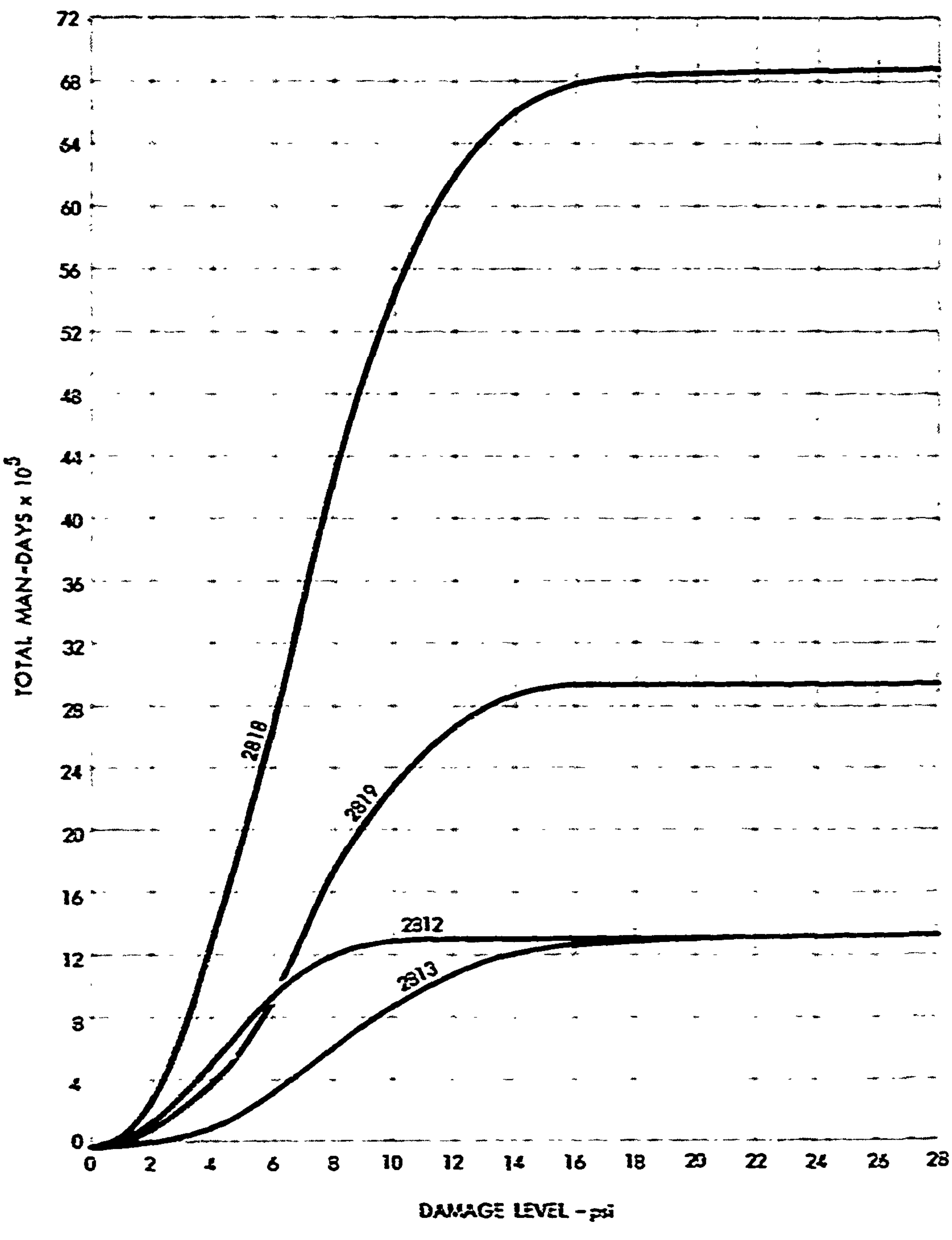


Table 8

REPAIR EFFORT FOR 281 INDUSTRY GROUP

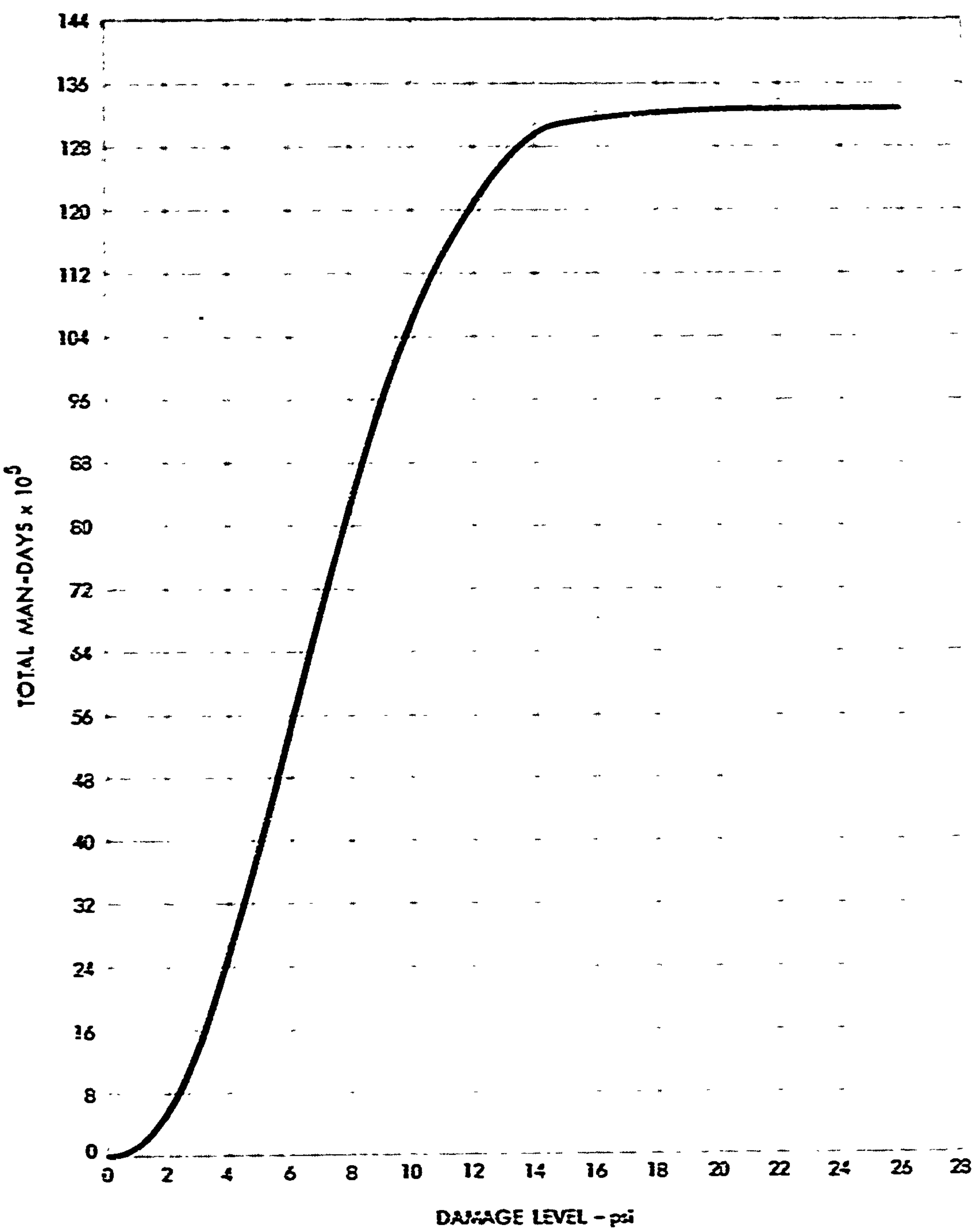
Industry by SIC Code	1965 Production of Chemicals (Millions of Tons)	1965 MVA (Millions of $)	Total Repair* Effort for Industry in Man-Days x 10^6	Repair Effort for Industry in Man-Days Per Annual Ton**	Repair Effort for Industry in Man-Days Per $1,000 MVA**
2812	19.9	442.0	0.80	.040	1.81
2813	15.0	352.0	.76	.051	2.16
2815	8.6	687.5	0.39	.045	0.57
2816	1.4	320.8	0.06	.042	0.18
2818	32.6	3,524.4	3.46	.105	0.98
2819	68.4	1,961.1	1.52	.022	0.78
Total	145.9	7,296.8	6.98	.048	0.96

* Repair effort at delta damage level.

** The figures presented in these two columns could be used for repair effort for segments of the industry.

Figure 11

REPAIR EFFORT VERSUS DAMAGE LEVEL FOR THE 281 INDUSTRY GROUP



Repair Effort for 281 Industry Group Based on Geographical Distribution

Based on the geographical distribution discussion of Section I, it might be expected that a nuclear attack concentrated on the SMSAs would leave approximately 30 percent of the 281 industry group production capability unscathed. The repair effort required for such an attack may be discussed in terms of Figure 11 to give the following example: assuming that all exposed establishments in the 281 industry group experience a damage level of 3 psi, the total required repair effort would be approximately 900,000 man-days. If the overpressure level were raised to 4 psi, the repair effort required would nearly double to over 1.5 million man-days.

Comparison of Repair Effort with New Construction Effort

For the electric utility industry, it was found [1] that the maximum repair effort required after nuclear attack approached new construction effort (not including site preparation but including debris removal). To check this parameter for the chemical industry, the data shown in Table 9 were assembled for four of the five typical plants studied. In all but one case, maximum repair effort costs exceeded the estimated new construction costs, reaching a maximum of 240 percent for a sulfuric acid plant. The reason for the wide variation (65 percent to 240 percent) is not immediately apparent, but, when plotted (Figure 12) the complexity of the plant (as measured by capital cost in dollars per ton per day of rated capacity) is found to vary regularly with the ratio of repair effort to capital cost. Figure 12 can be used to make gross approximations of maximum repair effort when only plant size and capital costs are known, affording a useful tool for estimation purposes when little information is available. For example, if the cost of a given plant were known to be \$5,000 per ton/day of rated capacity, the estimated maximum repair effort would be (Figure 12):

$$0.0040 \frac{\text{man-days}}{\$} \times \$5,000 = 20 \text{ man-days (per ton/day of capacity)}$$

The data from Table 9 and Figure 12 serve to confirm the validity of our repair estimates since we find, as with the gas and electric utilities, that maximum repair effort costs approach or exceed new construction costs. For cases in which repair effort exceeds new construction effort appreciably, it is hypothesized that we are dealing with components that are readily constructed initially but are most difficult to re-structure after damage. Similarly, for some items of equipment, perhaps even for entire plants, it may be necessary to decide whether complete razing might not be most advantageous when damage

Table 9

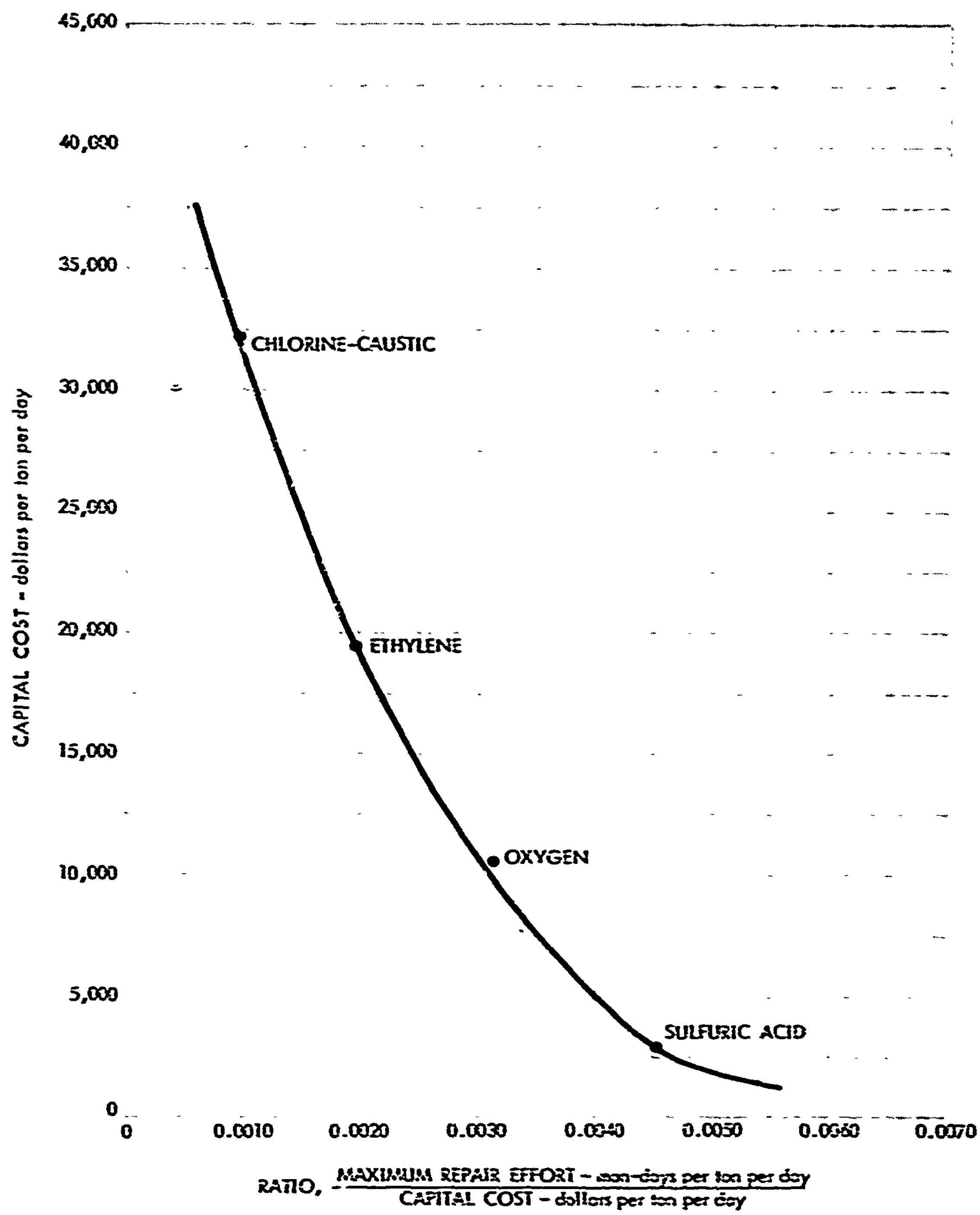
REPAIR EFFORT AS A FUNCTION OF TOTAL PLANT COST

Plant	① Capital Costs ($ per T/D)*	② New Construction Labor Costs ($ per T/D)**	③ Repair Effort (man-days per T/D)†	③ / ① Repair Effort as a Fraction of Capital Cost	④ Repair Effort Costs ($ per T/D)††	④ / ② Repair Cost as a Fraction of New Construction Cost
Chlorine-Caustic	32,000	2,240	31.4	0.000081	1180	0.53
Oxygen	10,500	735	33.0	0.003140	1170	1.60
Ethylene	19,200	1,340	37.4	0.001950	1400	1.00
Sulfuric Acid	2,580	181	11.6	0.004500	440	2.40

* Data from Ref. 25 with plant size changed, where necessary, to correspond to the plants of Table 8.
** Based on labor costs being 7 percent of capital cost for construction [18].
† Based on maximum repair effort (from Table 8) for typical size plants.
†† Based on labor costs of $4.70/hr [18].

Figure 12

PLANT REPAIR EFFORT/TOTAL COST AS A FUNCTION OF TOTAL COST



is severe. (Of course, razing would not apply to underground components and foundations which could be salvaged.)

Another check on the magnitude of our repair estimates can be made by comparing the maximum repair effort for the SIC 281 group (13.2×10^6 man-days from Figure 11) to the normal, ongoing construction activity of the SIC 281 group. Using the 1965 figures for capital construction costs [4] and a labor-to-construction ratio [18], it was possible to compute the actual man-days of labor that went into the new construction effort. The results are given in Table 10 which shows that the new construction effort in 1965 was approximately 20 percent of the maximum repair effort that would be required for the 281 industry group. In other words, if the "normal," undamaged capability of the chemical construction industry could somehow be directed to reconstructing the heavily damaged SIC 281 industry, the required repair time would be approximately 5 years.

Table 10

COMPARISON OF 1965 CONSTRUCTION EFFORT IN THE 281 INDUSTRY GROUP WITH REPAIR EFFORT

281 Industry Group	Man-Days of New Construction Effort in 1965* (10^3)	Repair Effort in Man-Days at 25 psi (10^3)	Ratio of New Construction Effort to Maximum Repair Effort
2812	139	1,350	0.103
2813	167	1,320	0.127
2815	151	730	0.206
2816	29	119	0.243
2818	1,520	6,860	0.222
2819	694	2,878	0.216
Total	2,610	13,209	0.197

* Excludes man-days required for foundation work and painting and in-plant employees engaged in routine repair activities. Typically this latter force is small and would not increase the "New Construction Effort" total appreciably.

Comparison of Results

Advanced Research, Inc. has conducted two studies [14,26] dealing with damage and repair of manufacturing industries—the food industry group (SIC-20) and the petroleum industry group (SIC-29). Although the food and chemical groups have little in common, some equipment is similar (e.g., heat exchangers, storage tanks, vacuum filters etc.). However, it was impossible to compare results of the above study with those obtained in this study, for two reasons: the repair estimates concentrated mainly on building repair with little emphasis on equipment, and even when repair estimates for equipment of interest were given, they were only gross estimates.

The petroleum industry group is similar to the petrochemical industry (SIC 2818) and employs comparable equipment in its processes. Although the Advanced Research study of petroleum refineries [14] concentrated on damage and repair of equipment, it was very difficult to compare results since a number of specific items of auxilliary equipment (e.g., heat exchanger) were not enumerated by Advanced Research for the processes they studied. In only two cases was direct comparison possible; in these cases the repair efforts reported by Advanced Research for repair of cylindrical storage tanks and a cooling tower checked within 20 percent of the repair efforts for similar size equipment derived in this study. In a third case, by making some assumptions as to auxilliary equipment, it was possible to compare results for an 80,000 barrel/day crude still*; in this case, the Advance Research results were a factor of 2 higher than our results. Although these comparisons indicate reasonably good agreement for the cases cited, the Advanced Research results for the petroleum industry are of limited usefulness for our purposes because of the lack of identification of process equipment and the failure to include information on support and auxilliary components (such as controls, utilities, and pipe racks).

A recent SRI study, a part of the National Entity Survival (NES) Study [27] investigated repair effort as a function of damage for various manufacturing segments of the economy. Included in this study was the SIC 28 major group (chemicals and allied products) of which the SIC 281 industry group is a part. By using the ratio of the SIC 281 MVA to the MVA of the SIC 28 major group, it was possible to derive a repair effort for the SIC 281 industry group that could be compared with the results of this study. The outcome of this comparison shows that the SRI results, based on repair efforts (in man-days) per $1,000 MVA, were a factor of 2.2 and 2.6 greater for overpressures of 3.4 psi and 5.5 psi, respectively, than

* The crude still process was assumed to consist of two towers or columns, various heat exchangers, pumps, and piping.

were the results of the present study. This agreement is remarkably good for estimates based on two such different bases. The present results have greater validity, however, for they are based on detailed analyses rather than, as for the NES results, on the extrapolation of limited data to a related, but nonhomogeneous, industry (i.e., SIC 28 group). The current findings, especially the considerably lower repair effort, should be incorporated into the NES study as soon as possible.

VII

TIME-PHASED REPAIR AND SKILLS

VII

TIME-PHASED REPAIR AND SKILLS

The time-phased repair analysis was performed to determine repair requirements in terms of both man-days and manpower skill classification. It also provided information on the number of workers required during any given work period (8-hour shift) and how their skills would be scheduled throughout the course of the repair program.

The time-phased repair sequence was prepared for the five typical establishments at the delta damage level for each plant, that is, at the overpressure level for which 50 percent of the maximum repair effort is required.

Procedure

The Repair Analysis Sheets (Appendix E), the mathematical models for each typical plant, and the experienced judgment of the Rogers Engineering staff, provided the basis for time and manpower skill schedules. It was necessary to balance such factors as crew size, working space, type of repair, equipment requirements, and job completion time to arrive at realistic repair schedules. From such basic information, time-phasing for repair of each plant was estimated and total manpower requirements for each plant was determined. These time-phase repair sequences were estimated only for qualified work crews and assumed availability of specialized equipment, replacement parts, and supplies.

Since most chemical plants are relatively small in area, uniform overpressure levels throughout the plant were assumed. Only the critical and semicritical chemical and auxiliary components were considered for the time-phased repair analysis in each typical establishment. As indicated in Section VI, disregard for the noncritical components implies that plants are restored to only 90 percent of their preattack production capability.

Results

Figures 13 through 17 present the work schedules by skill for each of the typical plants at their delta damage levels. The results have been presented as the total number of 8-hour work shifts required for each labor skill; thus, the total elapsed time required to repair a typical plant could be determined by deciding how many work shifts per day would be usefully employed.

Figure 13

TIME-PHASED REPAIR FOR CHLORINE-CAUSTIC PLANT AT 5 PSI

LABOR SKILL CLASSIFICATION	NUMBER OF SHIFTS (10, 20, 30, 40, 50, 60, 70)
Boilermakers	4 Number of Men per Shift
Bricklayers	1
Carpenters	2
Electricians	5 4 3 10 4
Equipment Operators	14 16 15 7 1
Insulators	1
Ironworkers	20 22 34 29 4
Laborers	4 6
Millwrights	3
Pipe Fitters	20 22 23 26 32 22 2
Riggers	28 29 28 29 27 21 24 4
Truck Drivers	1
Welders, Certified	5 6 4
Welders	20 21 20 27 18 6
TOTALS	

NOTE: Shift length = 8 hour, i.e., 1 man-day = 8 man hour.

A.

NUMBER OF SHIFTS (50, 60, 70, 80, 90)	TOTAL MAN-DAYS OF SKILL REQUIRED	PERCENT OF EFFORT	MEN PER SHIFT: AVERAGE	MEN PER SHIFT: MAXIMUM
per Shift	88	1	4	4
1	8	<1	1	1
	40	<1	2	2
3 10 4	287	4	5.3	10
7 1	696	10	13.4	16
1	21	<1	1	1
29 4	1,280	18	20.6	34
6	272	4	4.4	6
	15	<1	3	3
32 22 2	1,399	20	21.5	32
27 21 24 4	1,592	23	24.5	29
	6	<1	1	1
4	112	2	5.3	6
13 6	1,126	16	18.2	27
	6,942		125.2	

B.

Figure 14

TIME-PHASED REPAIR FOR LIQUID AIR PLANT AT 9 PSI

LABOR SKILL CLASSIFICATION	NUMBER OF SHIFTS (10, 20, 30, 40, 50, 60, 70)
Carpenters	2 Number of Men per Shift
Electricians	12 11 8 10 7 6 2
Equipment Operators	4 8 2 1
Insulators	9 4 1
Ironworkers	5 7 5 3 1
Laborers	8 4 6 4
Millwrights	1 2
Pipe Fitters	22 18 22 15 8 4
Riggers	6 8 2
Truck Drivers	1
Welders, Certified	9 16 5 2
Welders	4 9 6 8 6 1
TOTALS	

NOTE: Shift length = 8 hour, i.e., 1 man-day = 8 man hour.

A.

NUMBER OF SHIFTS (50, 60, 70, 80, 90)	TOTAL MAN-DAYS OF SKILL REQUIRED	PERCENT OF EFFORT	MEN PER SHIFT AVERAGE	MEN PER SHIFT MAXIMUM
	80	2.3	2	2
6 2	419	14	7.1	12
	155	5	3.4	8
4 1	202	7	5.6	9
1	230	7	3.6	7
	196	6	5.6	8
	79	3	1.9	2
8 4	854	28	14.5	22
	226	7	6.5	8
	25	1	1	1
2	383	12	6.5	10
	235	8	5.2	9
	3,08[illegible]		62.9	

B.

Figure 15

TIME-PHASED REPAIR FOR ETHYLENE PLANT AT 7 PSI

LABOR SKILL CLASSIFICATION	NUMBER OF SHIFTS							
	10	20	30	40	50	60	70	
Boilermakers				8 Number of Men per Shift				
Boilermakers' Helpers					4			
Bricklayers							32	
Carpenters					8			
Electricians		23		12				13
Equipment Operators	6	9	6	4		1		
Insulators					6		8	
Ironworkers	4	12	13	12		11 13		
Laborers	40			8				9
Millwrights	2	1					2	
Pipe Fitters		38	40		38		33	
Riggers	2	5	4			1		10
Truck Drivers					2			
Welders, Certified		24	27	25	24		16	
Welders	4 12	7		4		8		1
TOTALS								

NOTE: Shift length = 8 hour, i.e., 1 man-day = 8 man hour.

A1

NUMBER OF SHIFTS (50 60 70 80 90)	TOTAL MAN-DAYS OF SKILL REQUIRED	PERCENT OF EFFORT	MEN PER SHIFT AVERAGE	MEN PER SHIFT MAXIMUM
...er of Men per Shift	504	5	8	8
	32	<1	4	4
32	1,310	12	32	32
8	736	7	8	8
13 4	1,033	9	12	23
1 5	459	4	6.2	9
8 6 2	416	4	6.1	8
11 13 2	703	6	7.6	13
9 9	944	8	10.5	40
2	117	1	1.8	2
33 9 8	2,482	22	28.5	40
1 10 2	367	3	5.6	10
2	180	2	2	2
24 16 4	1,509	14	17.3	27
1 8 1	382	3	4.3	12
	11,174		1,539	

B.

Figure 16

TIME-PHASED REPAIR FOR AMMONIUM NITRATE AT 6 PSI

LABOR SKILL CLASSIFICATION	NUMBER OF SHIFTS (10, 20, 30, 40, 50, 60, 70)
Boilermakers	2 Number of Men per Shift
Bricklayers	1
Carpenters	2
Electricians	4 6 1 3 2
Equipment Operators	7 4 3
Insulators	1 3 1
Ironworkers	9 5 3 1
Laborers	2 1 2
Millwrights	1
Pipe Fitters	2 10 8 4 2
Riggers	2 4 2
Welder, Certified	3 6 4 1
Welders	8 4 2
TOTALS	

NOTE: Shift length = 8 hour, i.e., 1 man-day = 8 man hour.

A.

ER OF SHIFTS

50 60 70 80 90

TOTAL MAN-DAYS OF SKILL REQUIRED	PERCENT OF EFFORT	MEN PER SHIFT AVERAGE	MEN PER SHIFT MAXIMUM
10	>1	2	2
5	>0.5	1	1
30	3	2	2
130	12	3.6	6
90	8	4.7	7
40	4	1.7	3
171	16	5.5	9
32	3	1.5	2
30	3	1	1
220	21	5.5	10
62	6	2.4	4
109	10	3.2	6
138	13	5.3	8
1,067		39.4	

B.

Figure 17

TIME-PHASED REPAIR FOR SULFURIC ACID PLANT AT 8 PSI

LABOR SKILL CLASSIFICATION	NUMBER OF SHIFTS (10, 20, 30, 40, 50, 60, 70) — Number of Men per Shift
Carpenters	5, 4
Electricians	7, 8, 4, 10, 6
Equipment Operators	10, 8, 9, 10, 6, 4
Insulators	12, 2
Ironworkers	10, 14, 11, 3
Laborers	5, 12, 9, 8, 4
Millwrights	3, 8, 2
Pipe Fitters	8, 36, 39, 38, 18, 16, 24, 14, 6
Riggers	10, 11, 8, 7, 6
Welders, Certified	14, 4
Welders	10, 11, 10, 4, 2
TOTALS	

NOTE: Shift length = 8 hour, i.e., 1 man-day = 8 man hour.

A.

NUMBER OF SHIFTS (50, 60, 70, 80, 90)	TOTAL MAN-DAYS OF SKILL REQUIRED	PERCENT OF EFFORT	MEN PER SHIFT AVERAGE	MEN PER SHIFT MAXIMUM
4 **Number of Men per Shift**	298	4.8	4.3	5
4 10 6	366	5.9	6.9	10
6 4	574	9.2	8.2	10
2 2	322	5.2	7.0	12
14 11 3	674	10.8	9.6	14
4	465	7.5	6.6	12
2	221	3.5	3.6	8
18 16 24 14 6	1,815	29.1	25.2	39
7 6	416	6.6	8.0	11
4	526	8.3	9.7	14
0 4 2	571	9.2	8.2	11
	6,248		97.3	

B.

Figure 13 represents the time-phased work schedule for the chlorine-caustic plant at the 5 psi damage level. The plant required 66 work shifts to complete repair and used 14 different labor skills. Riggers, pipe fitters, and ironworkers represented 61 percent of the total work force.

Figure 14 depicts the oxygen plant time-phased repair sequence at the 9 psi damage level. Sixty-four work shifts were needed to repair the plant and 12 separate skills were used. Pipe fitters, electricians, and certified welders constituted 54 percent of the total work force.

Figure 15 illustrates the time-phased repair sequence for the ethylene plant at the 7 psi delta damage level. Fifteen separate labor skills and 98 work shifts were required. Pipe fitters, certified welders and bricklayers constituted 47 percent of the total work force.

Figure 16 indicates the time-phased repair sequence for the ammonium nitrate plant at the 6 psi delta damage level. Forty-two work shifts and 13 separate labor skills were needed to place the ammonium nitrate plant back in operation. Pipe fitters, ironworkers, and welders represented 50 percent of the total work force.

Figure 17 illustrates the time-phased repair sequence for the sulfuric acid plant at the 8 psi delta damage level. Seventy-six work shifts and 11 labor skills were needed to repair the sulfuric acid plant. Pipe fitters, ironworkers, and equipment operators constituted 50 percent of the total work force.

The ethylene plant repairs required the longest time period while the ammonium nitrate plant required the least time to restore production. The number of different skills required for repair varied for each of the typical establishments; however, 11 of the 15 labor skills utilized were common to all five typical plants. Pipe fitters accounted for at least 20 percent of the total repair effort in all of the typical plants, with ironworkers and both classifications of welders the next most important skills. The time-phased repair sequences are based on having the required labor skills available; if alternate skills would have to be used, the time periods needed to repair the plant would increase.

Critical Skills

The time-phased sequencing has shown which labor skills would be in the greatest demand, that is, which skills would have to contribute the greatest manpower to repair the 281 industry group. This is one definition of a critical skill; however, a more accurate indication of a critical skill would be the percentage of the total manpower pool of a given skill required to repair the industry. For this study, this was ascertained by extrapolating the delineated labor skills in the time-phased, typical plant sequences to the 281x industry which each typical establishment

represented. The extrapolation was carried out on the basis of annual production of the typical establishment versus the annual production of respective industry.* The availability of a specific labor skill (the total number practicing that labor skill in the United States) was based on the United States 1969 Census of Population, Detailed Characteristics [28]. Eight categories of labor skills were examined for their criticality instead of the 14 labor skills used in the time-phased sequencing. Six labor skills were not included for two reasons: (1) the total demand of some of these skills was less than one percent of the total skilled manpower (for example, millwrights), or (2) the census data either did not delineate that specific skill or combined it with another skill (for example, welders were not listed in their various subclassifications).

281x Industries

Figure 18 illustrates the relative criticality of various labor skills in the 2812, 2813, 2818, and 2819 industries. The figure is based on all establishments of each industry damaged to the delta damage level and the availability of preattack quantities of labor skills as shown in Table 11. Equipment operators/riggers and ironworkers are the two most critical skills in the 2812 and 2813 industries. Boilermakers are the most critical in the 2818 industry (almost 25 percent of the boilermakers in this country would be required to repair that industry). In the 2819 industry, boilermakers, equipment operators/riggers, and ironworkers are the most critical.

281 Industry

Figure 19 summarized the critical skills of the 281 industry group and includes subgroup industries 2815 and 2816. The subgroup inclusion was based on their annual production and its ratio to the annual production of the 281 industry group. It was assumed that these two industries would require the same distribution of skilled labor as the other four industries studied. Figure 19 is based on all establishments of the 281 industry damaged at the delta damage level versus the preattack availability of the eight different skills. Three labor skills—boilermakers, equipment operators/riggers and ironworkers—each had to supply over 25 percent of their preattack labor force to repair the 281 industry group.

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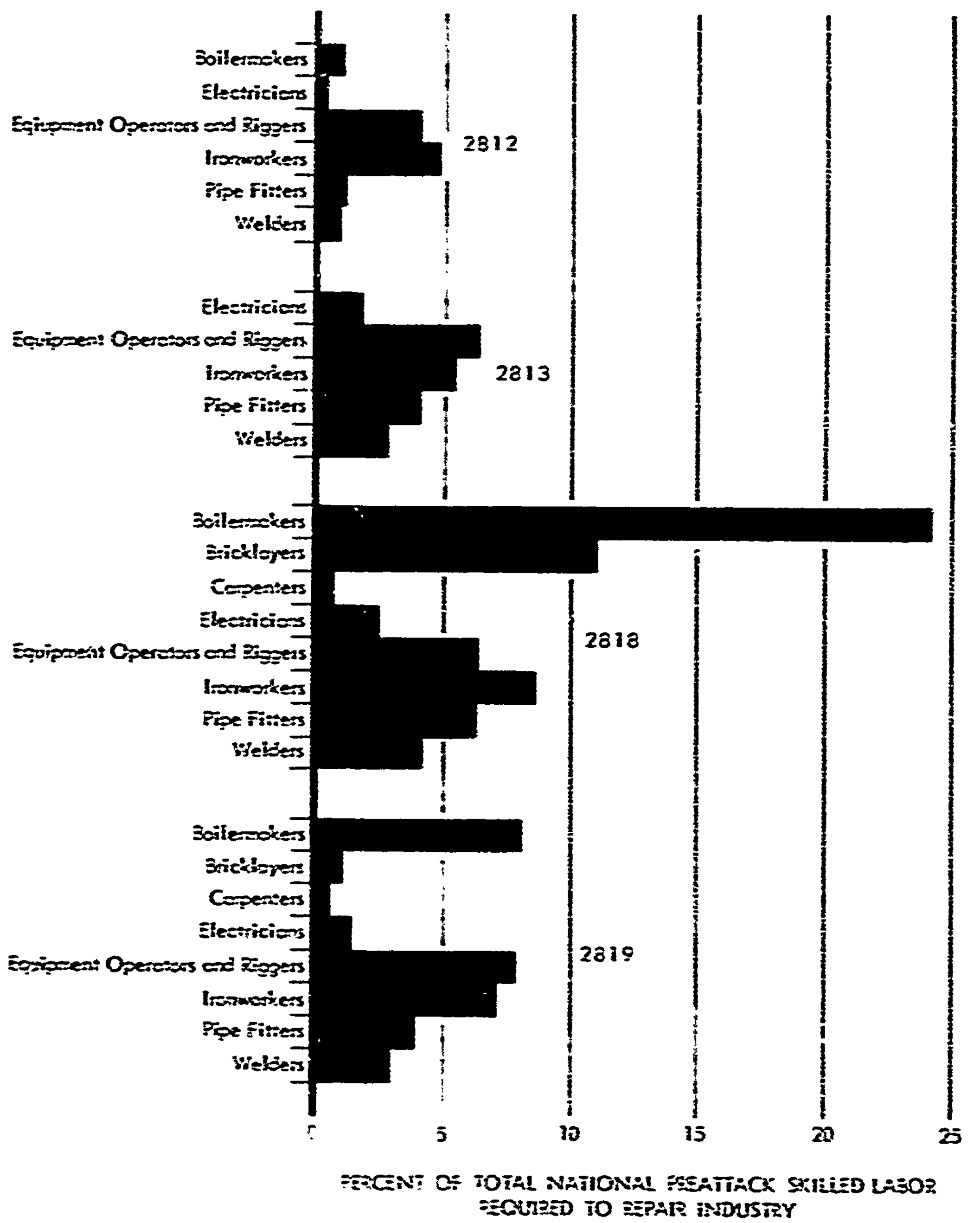
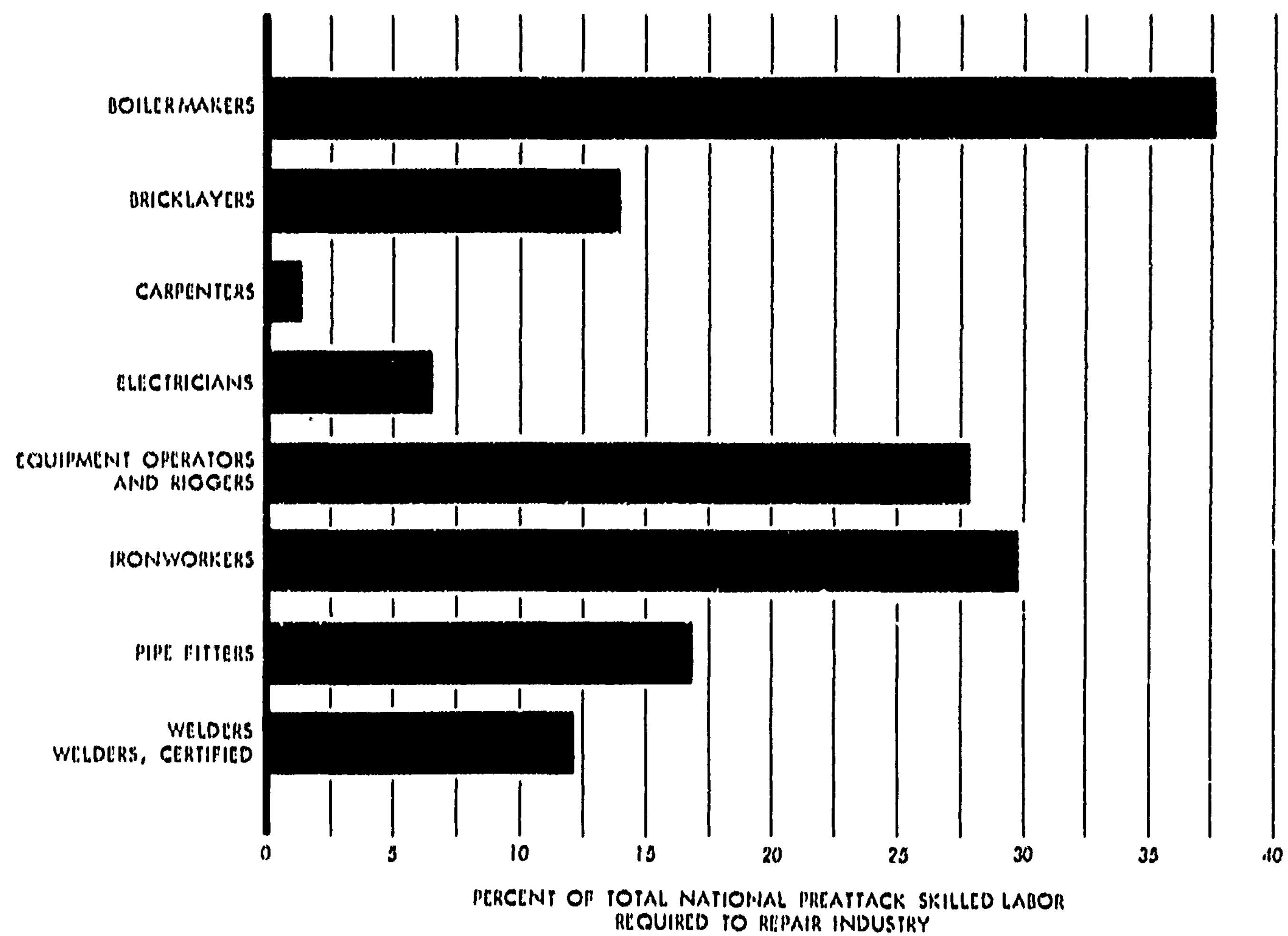
* The 2819 industry includes the manufacture of both liquid and solid chemicals. Ammonium nitrate was used to represent the solid chemicals portion (approximately 67 percent) of the 2819 industry on an annual production basis. Sulfuric acid (approximately 21 percent) was used to represent the liquid chemicals portion of the 2819 industry production, except for ammonia manufacture. Ammonia, which accounts for 12 percent of the 2819 industry annual production, was approximated by using the ethylene plant that contains chemical equipment modules more representative of ammonia manufacture than the other 2819 establishments.

Figure 18

REQUIREMENTS FOR CRITICAL SKILLS FOR THE SIC 281x INDUSTRY GROUP FOR DELTA DAMAGE LEVEL



Assumed: 100 percent of industry severely damaged, no skilled labor casualties



Assumed: 100 percent of industry severely damaged, no skilled labor casualties

Figure 19

REQUIREMENTS FOR CRITICAL SKILLS FOR THE SIC 281 INDUSTRY GROUP FOR DELTA DAMAGE LEVEL

Table 11

1960 U.S. CENSUS DETAILED CHARACTERISTICS

	Total No. in U.S. A.		Total No. in U.S.A.
Boilermakers	23,713	Ironworkers	57,987
Bricklayers	191,169	Pipe Fitters	303,541
Carpenters	816,195	Welders (certified and others)	344,385
Electricians	334,732		
Equipment Operators and Riggers	123,335		

Parametric Analysis of Industry Destroyed and Population Killed

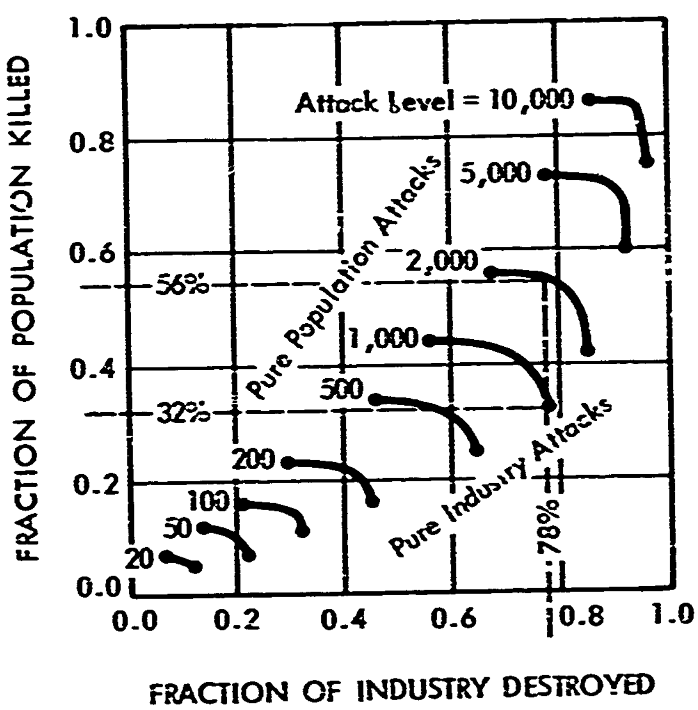
The previous figures assumed that all establishments of the industry were damaged to the median damage level and all of the preattack industrial population was available for making repairs. A more realistic appraisal would assume a mix between these two states, that is, certain percentage of the industry destroyed versus a certain percentage of population killed. The Lambda Corporation [29] derived a relationship for fraction of population killed versus fraction of industry destroyed for various levels of nuclear attack. Figure 20 depicts this relationship. Utilizing this information, a parametric analysis was performed to determine the impact of labor availability versus industries destroyed. Three attack levels—500 mt, 1,000 mt, and 2,000 mt—were used, and corresponded to three population versus industry mixes indicated by the dashed lines on Figure 20. Figure 21 illustrates the results of this parametric analysis. In the worst case (the 2,000 mt attack), over 50 percent of the surviving boilermakers, ironworkers, and equipment operators/riggers would be required to repair the 281 chemical industry group. As indicated in the Introduction, the degradation of demand for chemicals as a result of the attack is not considered and it is assumed that skilled labor experiences the same casualty rate as the general population.

The basic chemical industry, although essential to the economy of the country, represents only a small segment of the total manufacturing capability of the United States. The MVA for the 281 chemical industry group was approximately 3 percent of the MVA for the entire U.S. manufacturing industry in 1963. However, during the same year the 281 industry group did account for 6.5 percent of the Manufacturing Industries New Construction [30].

The percent of labor skills normally employed in the 281 industry group is indicated by the shaded area of the bar graphs in Figure 21 as a percentage of

Figure 20

FRACTION OF UNSHELTERED DAYTIME POPULATION KILLED AND INDUSTRY DESTROYED FOR DIFFERENT ATTACK OBJECTIVES



SOURCE: Lambda Corporation (Reference 29).

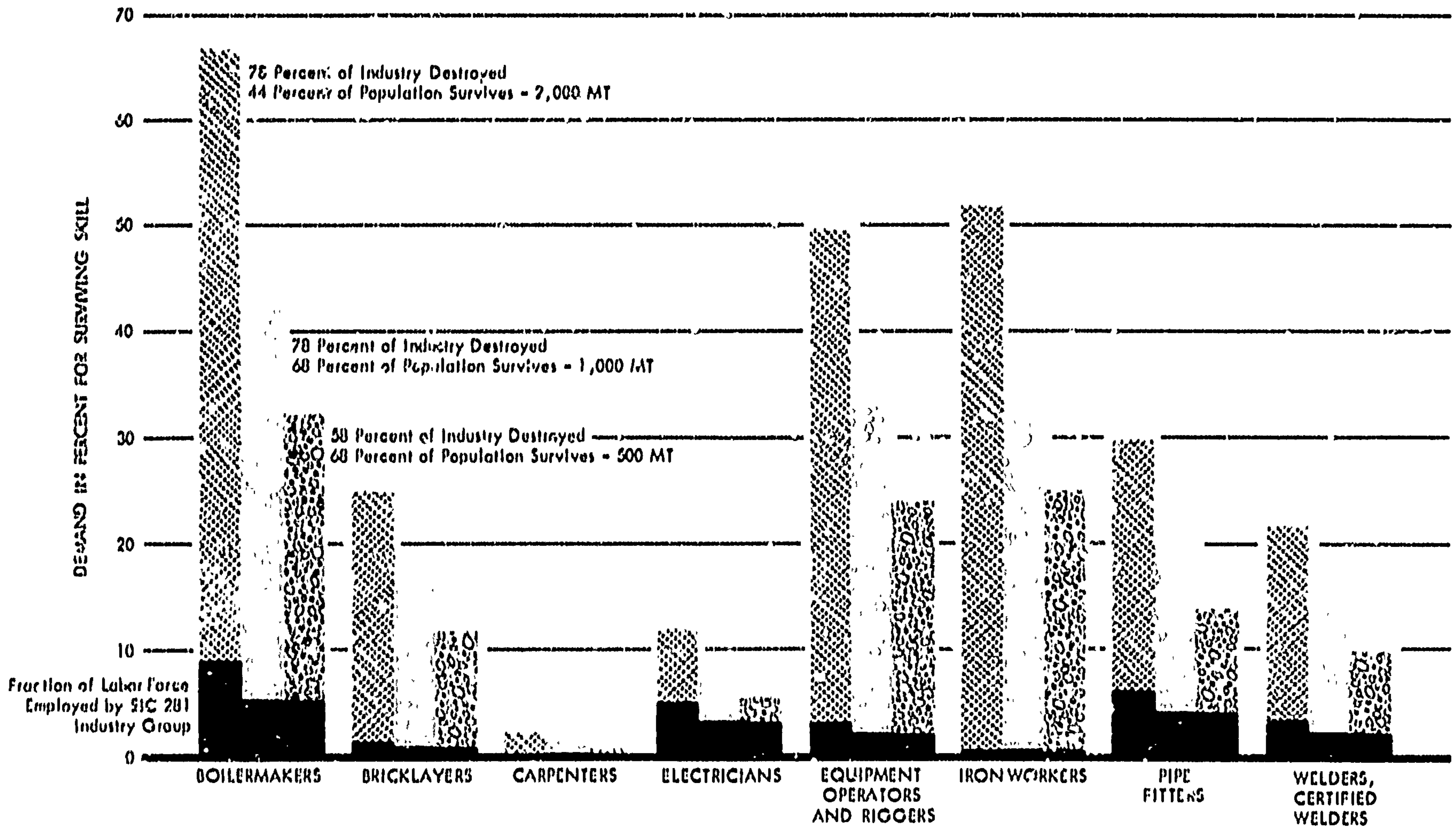


Figure 21

PARAMETRIC ANALYSIS OF INDUSTRY DAMAGE VERSUS LABOR SKILLS SURVIVING FOR 281 INDUSTRY GROUP

survivors. For example, using the 2,000 mt attack in which 44 percent of the population survives, 6 percent of the surviving pipe fitters would represent the number of pipe fitters normally used in the 281 industry group for construction and maintenance. The remaining 24 percent of the surviving pipe fitters would have to be taken from other industries or jobs in order to repair the basic chemical industry. Under these conditions, it would appear that seven of the eight labor skills could be considered critical, and boilermakers, equipment operators/riggers, and ironworkers would head this list. It is interesting to note that under the straight time-phased sequencing of labor skills (based on the required number of men of any one skill) pipe fitters and welders were most in demand. However, personnel possessing these skills are more numerous and the demand would be less critical than that for the other labor skills.

Based on the previous figures,* it appears that the supply of certain labor skills would be inadequate to meet the demand in the postattack period, and that a source of alternative labor skills would be needed to perform the necessary repair tasks. However, we have not made a rigorous analysis of consumer demands for chemicals—that being outside the scope of the contract—so that the results given here are for maximum repair efforts required. A further study is needed to delineate, for several national attack conditions, the actual repair effort required to meet the surviving consumer demand. In a previous study [1], a qualitative examination of this problem indicated that part of this postattack demand for skilled labor could be met by people who possessed a latent skill through former occupation not declared in the current census. To delineate this latent capability, research in this area would be very important. Other alternatives would involve selective repair of a limited number of establishments or an elongation of the time scale for repair with the available manpower.

Typically, the majority of chemical plant expansion and construction is performed by the construction industry. With the heavy damage that could be expected following a nuclear attack, the chemical industry, lacking the capability to perform necessary repairs itself, would have to rely on the construction industry to supply the men and equipment required. Therefore, a further indication of critical skills and the magnitude of the repair problem can be ascertained by comparing the postattack demand for labor skills that the 281 industry group would place on the construction industry.

Figure 22 presents the results of an analysis showing the percent demand of surviving skilled labor employed in the construction industry that would be required to repair the 281 industry under the 1,000 mt attack le[illegible] conditions (Figure 20). The surviving labor skills in the construction industry were derived from the preattack quantity of labor skills [31]. As indicated, there would be an

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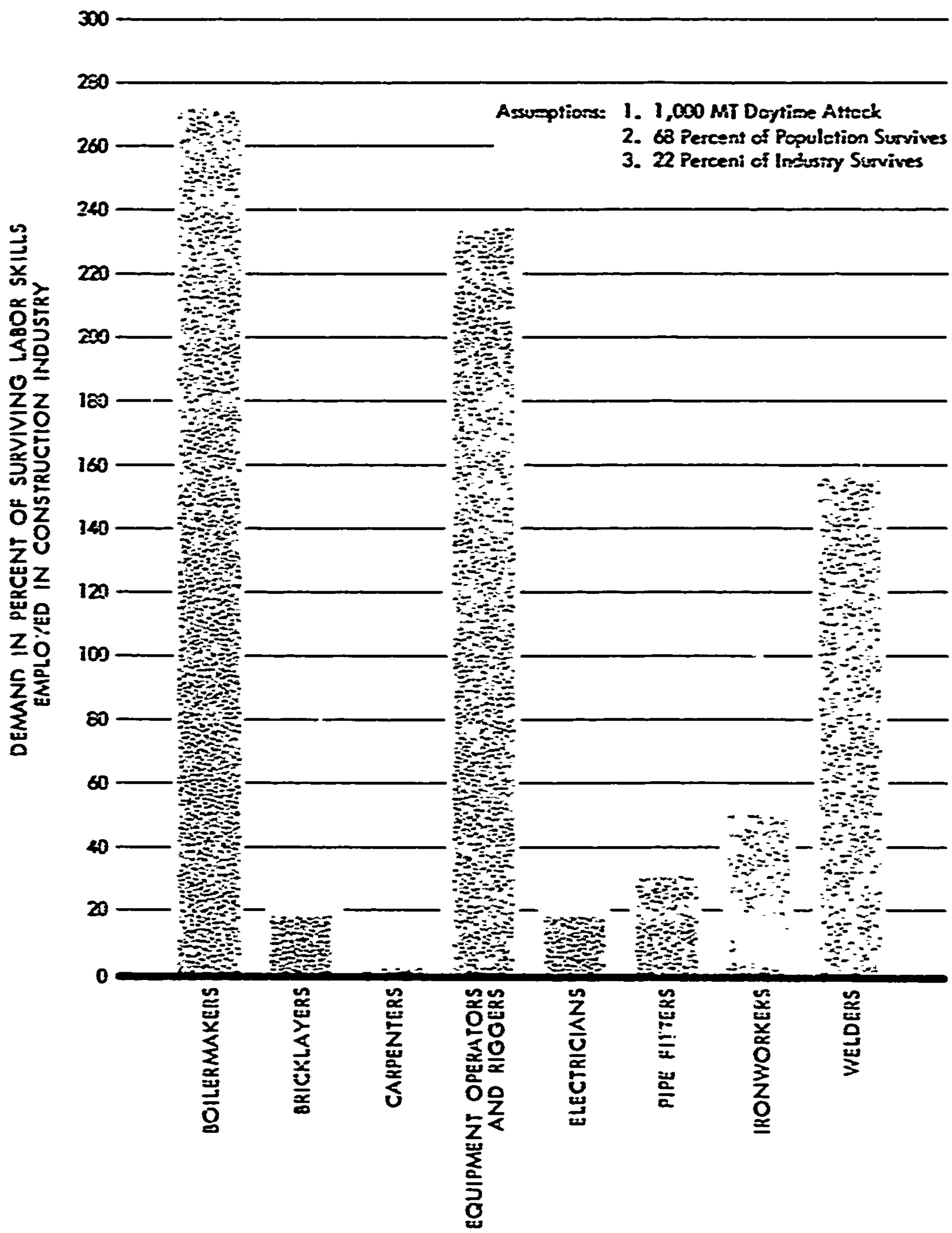
* In the recent National Entity Survival study [27], SRI stated that only a small fraction of the surviving labor force was required to restore the damage to the manufacturing industries. However, as the results of the critical skill analysis show, the type of labor (boilermaker, pipe fitter, or welder) is of greater importance than the total manpower available; thus even though SRI indicated a surplus of labor in general, a serious deficiency of skilled labor would exist postattack.

Figure 22

DEMAND ON THE SURVIVING LABOR SKILLS TO REPAIR THE 281 INDUSTRY GROUP



insufficient number of survivors in three labor skills (boilermakers, equipment operators, and welders) to meet the demand from the chemical industry, and two other skills (pipe fitters and ironworkers) require more than 30 percent of the construction industries' surviving supply. This means that the construction industry would be unable to meet the demands of the chemical industry (disregarding damage to any other segment of the manufacturing industry) and other sources of skilled labor would have to be found.

VIII

PROTECTIVE ACTIONS AND PREATTACK PLANNING

VIII

PROTECTIVE ACTIONS AND PREATTACK PLANNING

The type of chemical plant and its relative location would determine the degree of damage caused by a nuclear attack. It is pertinent, therefore, to consider the type of damage that could be expected at various overpressure levels, alternate modes of operation to re-establish the plant on line, any supply and equipment constraints germain to a typical plant, and preattack planning and protective actions a plant might undertake to improve its survivability under nuclear attack.

Chlorine-Caustic Plant

At very low overpressures (1 to 2 psi), the chlorine/caustic plant would suffer only minor damage, the most extensive would be the collapse of cylindrical storage tank roofs; the cooling tower, control system, and vacuum filters also would suffer minor damage. Although the plant itself would require some 1,000 man-days of repair effort, the greater part of this period would be spent in the repair of the storage tank roofs; this probably would not prevent plant start-up within two weeks after the attack.

At overpressure levels between 3 and 5 psi, more serious damage would occur. The diaphragm cells and chlorine dryer would be severely damaged and inoperable, the control cubicles and cooling tower would be destroyed, and the electrical system and vacuum filters would sustain heavy damage. The plant repair effort would require between 4,000 to 6,000 man-days and would be shut down for more than two months. At overpressure levels of greater than 8 psi, the plant would be considered destroyed and repair would be infeasible except under extraordinary circumstances. Cannibalization of some chemical equipment (heat exchanges, pumps, and compressors), however, might be possible and be of particular value when secondary efforts (such as fire and explosion) has caused scattered damage.

Oxygen Plant

At low overpressure (1 to 2 psi), damage to the liquid oxygen plant would be restricted to the controls and cooling tower. The plant would require only 100 man-days to repair and probably would be in operation within a week. At 3 to 5 psi, the plant would suffer light to medium damage, with the controls and cooling tower destroyed and the electric system damaged. Restoration of the plant to an

operating condition would require from three hundred to six hundred man-days and would take several weeks to complete. At higher overpressures (between 6 and 9 psi), the plant would suffer severe damage, with the loss of piping and pipe racks, destruction of the electrical system, and heavy damage to distillation columns, electric motor drives, and refrigeration units. Two to three thousand man-days over six to eight weeks would be required to restore the plant. Overpressure levels in excess of 12 psi would make the plant infeasible to repair, as the majority of equipment would be destroyed; however, compressors, pumps, and heat exchangers probably could be salvaged.

Ethylene Plant

At low overpressure levels (between 1 and 2 psi), the ethylene plant would sustain light damage. However, the large cracking heaters necessary for the production of ethylene would be seriously damaged and the plant as a whole would require up to 3,000 man-days and six to eight weeks for complete repair. At somewhat higher overpressure levels (between 3 and 5 psi), the ethylene plant would suffer light to medium damage; the cracking heaters, control cubicles, and cooling tower would be destroyed and the electrical system damaged. Five to six thousand man-days of repair effort would be required to repair the plant and production would be halted for at least 10 to 12 weeks. At overpressure levels between 6 and 8 psi, severe damage would occur. Distillation columns and piping and pipe racks would be severely damaged or destroyed, electric motors would be damaged, and 12,000 to 14,000 man-days of repair effort would be required. At overpressure levels greater than 10 psi, repair of the plant would be infeasible, although compressors, pumps, and heat exchangers probably could be salvaged.

Ammonium Nitrate Plant

At low overpressure levels (1 to 2 psi), the ammonium nitrate plant would sustain light damage. The equipment elements damaged would be the atmospheric storage tanks, the control system, and the cooling tower. The repair effort would not exceed 200 man-days and would require only one to two weeks. At higher overpressure levels (between 3 and 5 psi), the plant would suffer moderate damage with the cooling tower and controls destroyed, and the package boilers, electrical system, solids storage bins, and barometric condensor suffering severe damage. Six hundred man-days of repair effort over a period of several weeks would be required. At overpressure levels between 6 and 8 psi, the plant would suffer severe damage; reactor vessels would be damaged, the conveying system destroyed, and the piping, package boiler, rotary kilns, and prilling tower severely damaged. Repair would require up to 1,600 man-days and six to eight weeks. Overpressure levels greater than 9 or 10 psi would make the plant

infeasible to repair, although pumps, heat exchangers, and pressure vessels might be cannibalized.

Sulfuric Acid Plant

At the 1 to 2 psi overpressure levels, damage to the sulfuric acid plant would be limited to the acid storage tanks, the control system, and the cooling towers. This damage would require over 1,000 man-days and over four weeks to repair. At higher overpressures (between 3 to 5 psi), the plant would suffer light to moderate damage. The storage tanks, cooling tower, and control cubicles would be destroyed and the electrical system and air blower damaged. The repair effort would require from 1,500 to 2,000 man-days over a period of six to eight weeks. At overpressure levels between 6 and 9 psi, the sulfuric acid plant would sustain severe damage. The acid absorbers, converters, and towers would be severely damaged and the piping, electrical system, and air blower would be destroyed. Six thousand to 8,000 man-days of repair effort would be required during a period of three to four months. At overpressure levels in excess of 12 psi, repair of the sulfuric acid plant would be infeasible; however, heat exchangers, steam turbine drives, and acid coolers might be salvageable.

Table 12 lists secondary hazards, supply and equipment constraints, alternate operating procedures, and possible damage due to uncontrolled shut-down for the five typical establishment studied.

281 Industry

The 281 basic chemical industry group could reduce its overall vulnerability to damage from a nuclear weapon attack by judicious planning and preventive measures. Preattack plans should include procedures on a safe, orderly shut-down of the plant's chemical processes, provisions for specific employees to be sheltered on the premises (to handle postattack contingencies), and procedures for taking precautionary actions to protect the plant and equipment. Examples of precautionary actions that would help to reduce the vulnerability of a chemical plant are:

- Harden control rooms and controls whenever possible (using sandbags, etc.).
- Shut down plant in an orderly, systematic manner [32].
- Fill vessels and tanks with water or the product to increase resistance to overturning.

Table 12

ESTABLISHMENT TYPICAL CONSTRAINTS

Establishment	Secondary Hazards	Equipment and Supply Constraints	Alternate Postattack Operating Procedures	Damage Possible for Uncontrolled Shut-down
Chlorine-Caustic	Leakage of Cl_2 gas. Leakage of hot caustic solution	1. Carbon Anodes 2. Nickel Components	1. Use one of three multiple effects evaporator, reduce capacity 2. Bypass barametric condenser, reduce quality of product 3. Bypass filters in brine line 4. Use only three-fourths of acid driers	Fouling and plugging of pipelines [32]
Oxygen	Liquid oxygen spill could cause explosion	1. Cellulube 2. Compressor Parts	1. Bypass compressors--make only gaseous oxygen 2. Bypass dryers in air intake line will lower efficiency	None*
Ethylene	Fire from spilled ethylene [33]	1. Compressor Parts	1. Use only one dehydrator (reduces efficiency)	Fires and explosions [32]

(continued)

Table 12 (concluded)

Establishment	Secondary Hazards	Equipment and Supply Constraints	Alternate Postattack Operating Procedures	Damage Possible for Uncontrolled Shut-down
Ammonium Nitrate	Leakage of ammonia or nitric acid	1. Stainless Steel Components	1. Bypass one evaporator reduce capacity 2. Bypass coating drum - degrades product 3. Bypass drying - reduces quality of product	None *
Sulfuric Acid	Leakage of sulfuric acid or sulfur tri-oxide gas		1. Bypass either drum or acid absorption towers could make only 1 grade of acid	Corrosion, fouling, and plugging of pipelines [32]

* Reasonable responses of safety equipment frequently with redundant functions shut these units down safely. The statistical possibility of a high order of safety equipment failure exists. However, this is not considered significant.

Source: URS Corporation, Rogers Engineering Co., Inc.

- Utilize missile barricades (steel mesh screens) around equipment that could be severely damaged by missiles (for example, glass-lined reactors).

- Protect sight glasses on equipment containing chemicals that are explosion hazards [34].

- Isolate (by valving) all storage tanks and vessels to prevent fire spreading from one to another through interconnections.

- Tie down reactor vessels, transformers, etc., to increase resistance to overturning.

A weak-link approach to hardening should be undertaken, that is, harden those chemical equipment elements that would suffer damage at the lower overpressure levels. (Attempting to harden all equipment in a chemical plant to resist damage above 5 or 6 psi probably would prove both expensive and difficult.)

Certain alternate operating procedures have been described for the five typical establishments in this study. The use of these interim measures would reduce the efficiency and capacity of the chemical manufacturing process and in most cases would usually lower the quality of the final product. The reliability and safety of a chemical process also would be degraded through the use of these alternate procedures. However, through the use of these procedures it is possible to regain some production capability in a shorter period of time.

Some general alternate operating procedures that would be applicable throughout the basic chemical industry are:

- Automatic controls—when automatic controls have been damaged, an alternate procedure is to resort to manual operation. While this would increase the size of operating crews by a factor of three or four, manual controls would allow partial or full operation while an expedient control system was being rigged.

- Atmospheric storage tanks—when the roof on an atmospheric storage tank has been badly damaged, an immiscible floating liquid acting as a vapor barrier could be utilized in lieu of repair.

- Cooling tower—when a cooling tower has been completely destroyed, an alternate method of cooling can be arranged by bulldozing the debris of the cooling tower into the undamaged cooling tower basin and spraying the water over the debris. Although this expedient will considerably reduce the cooling capacity, it will return some cooling capability to a damaged plant.

A nuclear attack on this country would undoubtedly disrupt the normal channels of supply and transportation. Equipment supply and spare part constraints have been discussed previously for each of the five typical establishments. How this would affect the restoration time of a basic chemical industry would be very difficult to quantify and is beyond the scope of this report. However, it would be reasonable to assume that many spare parts and replacement equipment would be extremely difficult (if not impossible) to secure in the aftermath of a nuclear attack. The option remaining would be cannibalization and salvage of chemical equipment from several different plants to reactivate one plant. This probably would be the most feasible method of restoring production to the basic chemical industry.

Operation Versus Shut-down

The chemical equipment damage predictions and the secondary damage hazards tabulated in Table 15 were predicated on the assumption that the typical establishments were operating under normal conditions at the time of the nuclear attack. Insofar as blast-induced damage to chemical equipment is concerned, there appears to be no significant difference between the vulnerability of equipment in an operating condition versus a shut-down condition; however, vessels or tanks supported on columns will fail at lower overpressures if emptied of contents. (Damage estimates were performed for tanks and vessels in the full and empty condition and are notated as such in the damage/repair catalog, Appendix E.) A more important aspect [32], however, is the nature of the chemicals contained in the equipment when subjected to blast overpressures. Many of the chemicals manufactured in the basic chemical industry are noxious, toxic, or flammable; if allowed to leak or spill to the atmosphere, serious secondary hazards could be created that would cause more severe damage to a plant and its personnel than would have been predicted by blast levels alone. Thus, precautionary measures would shut down a chemical plant prior to a nuclear attack, with pipelines and equipment being drained of their contents and water or some other inert fluids substituted in vessels, tanks, and distillation columns. This is a safety measure practiced in some areas of the country when a hurricane is expected [37].

Another possible hazard that was investigated briefly is the possibility of certain chemicals within tanks or vessels detonating when the tank or vessel containing the chemical is struck by missiles. However, the explosive susceptibility of chemicals is complicated and published information is limited mainly to those chemicals commonly classed as explosives [35 and 36].

IX

CONCLUSIONS AND RECOMMENDATIONS

IX

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Damage/Repair Catalog for Equipment

The catalog of individual chemical equipment components with corresponding damage and repair estimates was crucial to the development of study results. The existence of the catalog permitted accurate estimation of the repair requirements for actual establishments of the basic chemical industries. With this catalog, it is possible to estimate repair requirements for a wide range of manufacturing establishments--even those outside the chemical industry when the required equipment is added to the catalog.

Mathematical Models for Relation of Repair Effort with Damage Level

Repair estimates for the 46 chemical equipment components studied were calculated for a wide range of damage expressed in overpressure levels. A mathematical model was found that satisfactorily represented the calculated repair versus damage relationships for all equipment components when appropriate empirical constants are used for each component. The model includes a scaling factor relating the repair effort with equipment size or capacity, thus permitting the scaling of repair effort to the size of a given component.

Mathematical models were developed to relate repair effort and damage level for the four typical industries (SIC 2812, 2813, 2818, and 2819) as well as for the overall SIC 281 basic chemical industry group.

Repair Effort Required for Chemical Equipment Components

The repair effort required to restore damaged chemical equipment components generally reflected the complexity and vulnerability of the equipment. The type of repair required for equipment with a hard vulnerability classification usually included only realignment or resetting on foundations since little internal damage occurred. Medium or soft category components, on the other hand, usually experienced both internal and external damage and required additional types of repair.

Repair Effort for the SIC 281 Basic Chemical Industry Group

The maximum repair effort (for overpressures greater than 15-20 psi) required to restore the basic chemical industry group (SIC 281) was found to be approximately 13 million man-days. The damage level requiring 50 percent of this maximum repair effort was found to be about 7 psi overpressure. (The curve shape is very steep at this overpressure.)

The maximum repair effort represented from 50 to 240 percent of the new construction effort for the various industries of the basic chemicals group, validating the magnitude of our repair estimates. This repair effort corresponds to about five times the labor effort expended annually for new construction in the basic chemical industry group (for the year 1965). To repair the entire industry—an unlikely eventuality if probable surviving consumer demand were to be considered—would overwhelm the surviving repair capabilities. However, even a selective, limited repair effort would be likely to encounter constraints and shortages of a long-term nature.

An interesting relationship relating plant capital costs to the ratio of maximum repair effort over total cost was identified. In this relationship, the plant capital costs could be considered an index of plant complexity. Although this relationship probably is useful only for gross approximations, it can be a tool for estimating repair requirements.

Skilled Labor Requirements

It appears that the supply of certain labor skills would be inadequate to meet the demand in the postattack period and that an alternate source of labor or skills would be needed. The most critical skills were found to be boilermakers, equipment operators/riggers, and welders. From previous investigation [1] it appears that there are a number of people with latent skills that could be utilized to meet the demand.

Preattack Planning and Precautionary Actions

Preattack plans should include procedures for plant shut-down, provisions for sheltering specific employees, and procedures to cover precautionary actions for protection of the plant and equipment.

Precautionary actions to help reduce chemical establishment vulnerability include: (1) harden controls and control rooms; (2) shut down plant safely; (3) leave vessels, tanks, and distillation columns full of water or other inert liquid; (4) protect equipment susceptible to missile damage with appropriate barricades; (5) protect sight glasses on equipment susceptible to explosion hazards; (6) isolate storage tanks and vessels to prevent fire spread; (7) secure tall equipment items with tie-down to reduce overturning vulnerability.

Vulnerability of Chemical Equipment Components

Chemical equipment components have been classified into three broad groupings according to damage vulnerability: soft, medium, and hard. Examples of the soft group (severe damage experienced below 5 psi) include controls, cooling towers, and storage tanks (except spherical). The medium group (severe damage occurring between 5 and 10 psi) includes items such as blowers, columns, and package boilers. Examples of the hard group (severe damage experienced above 10 psi) are heat exchangers, pumps, and spherical storage tanks.

Damage to equipment was identified according to the particular weapon effect producing the damage. In this regard, overpressure (diffraction phase) was found to be the major cause of damage for buildings, storage tanks, cooling towers, electrolytic cells, and controls. Dynamic pressure was found to be the major cause of damage for certain exposed components such as columns, process and pressure vessels, heat exchangers, pumps and drivers, compressors, most of the special equipment, package units, and piping.

Critical Chemical Equipment Components

It is not possible to assign a criticality rating to individual chemical equipment components in a general manner. A component may be critical in one particular application in a processing scheme and semicritical or noncritical in another. Equipment must be rated for criticality on an individual establishment-by-establishment basis.

Comparison of Study Results with Other Work

A portion of the National Entity Survival (NES) Study [28] examined repair effort for the SIC 28 major group. A comparison indicated the NES study results would be a factor of 2.2 to 2.6 times higher than the corresponding repair estimates of this study. Although the agreement between the results of these two studies is acceptable, the results of the present study, being better validated, should be incorporated into the NES model as soon as possible.

Geographical Distribution of the Basic Chemical Industries

One measure of the geographical distribution of these industries is related to their proximity to standard metropolitan statistical areas (SMSAs). An analysis of all establishments within the basic chemical industry group reveals that over 70 percent of the production capability is located in SMSAs.

The nature of the available information concerning geographical distribution of the basic chemical industries and the budget limitation for this contract have made it impossible to give a more meaningful presentation of such distribution in this study. With further research, however, it should be possible to uncover useful relationships.

Complexity and Interrelation of Chemical Establishments

The most modern chemical establishments tend to have increased use of automation in process control, and computer control systems are becoming more prevalent. These factors result in establishments more vulnerable to nuclear attack since control and control systems are relatively soft in comparison with more chemical equipment.

Another trend in modern plants is toward the interrelated plant or multichemical complex. In some cases, these plants have long interconnecting product pipelines, with related plants being 50 or more miles apart. In complexes such as these, vulnerability of production capability is increased due to dependence on interconnections with other establishments.

Classification of the Basic Chemical Industries

Due to the nature of existing establishments manufacturing chemical products, the classification of these establishments into specific groupings is rather arbitrary and the actual boundaries between such groupings are indistinct.

Recommendations

Based on the results and conclusions of this study, the following areas of future research are recommended.

1. Study in detail a large multichemical plant to determine more accurately the effects of nuclear attack on a chemical complex with many interconnected product lines.

2. Apply the appropriate mathematical models to the actual chemical establishments of the SIC 281 industry group present in the cities of the Five-City Study. Such a study would provide basic inputs for the post-attack recovery portion of the Five-City Study and provide a better understanding of the problems facing the basic chemical industry group.

3. Explore the application of the results of this study to other industries. By appropriate addition of new equipment items to the damage/repair catalog of this study, it should be possible to make estimates for the repair requirements of a wide range of industries outside the SIC 281 group.

4. Examine the decrease in demand for chemical products of the SIC 281 industry group that would result under various conditions of nuclear attack and the resultant changes in repair requirements caused by the changes in demand. This would require study of the interactions of these chemical products with industries outside the 281 group as well as the effects of population decreases and the damage experienced by other related industry groups.

5. Explore in more detail the potentially useful relationships among repair effort, capital costs, and degree of complexity for a wide range of chemical establishments. It appears that some significant shortcuts to repair estimation may be possible by relating these variables. Application to establishments outside the chemical industry also may be possible; this could facilitate repair estimates for the whole spectrum of manufacturing establishments.

6. Examine in depth the available information concerning geographical distribution of chemical industry establishments to uncover the controlling relationships.

7. Incorporate applicable portions of the results of this study into the NES model to yield more accurate predictions of industrial capacity and restoration.

8. Perform research into the existence of currently unreported labor skills that are possessed as a result of military service, former employment, or hobbies. The tabulation or estimation of the number of persons falling into the various labor-skill categories would provide useful information for restoration and reclamation studies.

X

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X

REFERENCES

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APPENDIX A

BIBLIOGRAPHY FOR CHEMICAL PROCESSES AND THE CHEMICAL INDUSTRY

APPENDIX A

BIBLIOGRAPHY FOR CHEMICAL PROCESSES AND THE CHEMICAL INDUSTRY

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APPENDIX B

SELECTION OF REPRESENTATIVE INDUSTRIES

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SELECTION OF REPRESENTATIVE INDUSTRIES

The selection process used in this study was guided by the criteria delineated in Section I and assisted by technical consultation with personnel from Rogers Engineering (subcontractor to URS Corporation). As indicated earlier, the selection was performed at the level of major industry numbers within the 281 group and also at the level of chemical products under the selected major industries.

First Selection Level

The six major industry headings were surveyed and four industries were selected as being most representative of the SIC Group 281 establishments as a whole. Each of the six industries is reviewed and the rationale for inclusion or exclusion is presented.

2812: Alkalies and Chlorine

Chlorine would be a very important chemical in the early postattack period because of its use in water and sewage treatment and also in the pulp and paper manufacturing industry. Sodium hydroxide also would be important in the early postattack period because of its use in the pulp and paper industry and in petroleum refining. In addition, both of these chemicals (chlorine and sodium hydroxide) along with sodium carbonate (another 2812 chemical) are extremely important due to large volume production and extensive use in manufacturing organic and inorganic chemicals. For example, they are used in the production of soap and detergents, fibers and plastics, glass, petrochemicals, pulp and paper, fertilizers, explosives, and solvents.

2813: Industrial Gases

Included in this group of chemicals are oxygen, acetylene, helium, hydrogen, and refrigerant gases. Oxygen and acetylene would be vital for immediate postattack recovery because of the need for metal welding and cutting. Oxygen and helium would be important for medical purposes. The supply of refrigerant gases also may be vital in the postattack period. Oxygen has become a high volume production chemical in the past ten years due primarily to its use in steel production, but it is also important in the manufacture of acetylene, ammonia, and methanol. Nitrogen is used in high volume also, and is employed in manufacturing ammonia and preventing rancidity in foods sealed in containers. Hydrogen is important for its use in ammonia synthesis, hydrogenating edible oils, and for electrical machinery and electronics.

2815: Cyclic Intermediates, Dyes, Organic Pigments, and Cyclic Crudes

The majority of products in this group of chemicals (dyes, color lakes and toners, and organic pigments) must be considered unimportant for the immediate recovery period. The few items of interest in the list (cyclic intermediates such as benzene and benzene derivatives) are products manufactured in much larger quantities in other manufacturing groups such as petroleum refining (specifically, the SIC 29 major group), or as byproducts (for example, from coke ovens).

2816: Inorganic Pigments

Since inorganic pigments would not be considered vital in the immediate postattack period, this group of industries is not of prime importance for our study. In addition, this group of products represents less than 5 percent of the manufacturing value added for all basic chemicals.

2818: Industrial Organic Chemicals

This group of products accounts for over 48 percent of the total manufacturing value added for all basic chemicals and contains a number of products considered important for immediate postattack recovery. Included in this list are chemicals such as: insecticides, hydraulic fluids, industrial alcohols, the basic raw materials for many important medical supplies, and petrochemicals.

2819: Industrial Inorganic Chemicals

This group of products includes about one-third of the manufacturing value added for basic chemicals and contains many chemicals important in the immediate postattack period. The most significant items include fertilizers, water treatment chemicals, disinfectants, explosives, raw materials for the manufacture of soaps and medicines, and chemicals necessary for paper production. The chemicals in this group are produced by a variety of processing equipment and techniques.

On the basis of this initial survey, Industry Numbers 2812, 2813, 2818, and 2819 were selected for the purpose of this study as most representative of the industry as a whole.

Second Selection Level

Having chosen four major industry headings, the next step was to select plants manufacturing chemicals in each of these industries that are representative of each of the four-digit SIC code industries (2812, 2813, 2818, and 2819).

2812: Alkalies and Chlorine

The chlorine-caustic soda (Cl_2 + NaOH) electrolytic process was chosen as representative and typical of the 2812 industry. Hydrogen manufacturing (a 2813

chemical) is included as a byproduct of this process. The reasons for this selection were:

- Chlorine and caustic soda comprise over 60 percent of the dollar value of products manufactured in the 2812 industry

chlorine	- \$124,821,000
NaOH	- \$147,040,000
Total Primary products (2812)	- \$415,963,000

- Chlorine and caustic soda are two of the most important basic chemicals in the industry and typically are made in the same plant.

- The electrolytic process used to make Cl_2 and NaOH is basically the same as that used to make some of the other chemicals in the 2812 industry--such as KOH (potassium hydroxide).

- Soda ash (sodium carbonate) is the third major chemical in the 2812 industry group. Twenty percent of the soda ash used in this country is produced from natural sources (Trona) while the remainder is manufactured by the ammonia-soda process or as a byproduct of the electrolytic process of chlorine-caustic soda.

2813: Industrial Gases

The production of oxygen and nitrogen from air was selected as the process to represent the 2813 (industrial gas) industry. (The production of argon will be included as a byproduct.) The reasons for this selection were:

- Oxygen is a basic reagent for many chemical and manufacturing processes (for instance steel making) and accounts for approximately one-third of the total 2813 industry sales.

- Nitrogen is manufactured from the same process as oxygen and, together with oxygen, represents 43 percent of the 2813 industry. By itself, nitrogen rates fourth in the industry in overall sales (11 percent).

- Acetylene, ranking second in industrial gas sales (24 percent of total sales), is used chiefly for the manufacture of other chemicals. However, other chemicals (such as ethylene) can be used in some instances as a feedstock in its place and acetylene used for welding can be made by using small portable acetylene generators fed by carbide. Therefore, it was not included in the typical 2813 plant.

- Carbon dioxide, ranking third in industrial gas sales (12.5 percent), was considered a noncritical chemical as 75 percent of the CO_2 produced for sales was used for refrigeration (many other refrigerant chemicals are available) and carbonated beverages. Therefore, it was not considered in the typical 2813 plant. Carbon dioxide is manufactured through natural gas or oil burning, or as a byproduct of other processes (urea, fermentation, etc.).

2818: Industrial Organic Chemicals

An ethylene production plant has been chosen to represent the 2818 industry. Reasons for this selection are given below.

- Ethylene is the largest volume-production chemical in the industry (about 5 percent of the 2818 total).

- Ethylene is a very important basic chemical and is the building block for many other large-volume chemicals, such as, ethylene dichloride, ethylene oxide, ethylene glycol, and polyethylene.

- The equipment and operations in the production of ethylene are basically the same as those used in the production of many other chemicals in the 2818 industry.

2819: Industrial Inorganic Chemicals

The industries selected as most representative of the 2819 group are ammonium nitrate manufacturing, and a sulfuric acid plant. The reasons for the selection of these particular industries are given below.

- Ammonium nitrate represents approximately 4.5 percent of the 2819 industry MVA and had a 1963 production of 4 million tons. Ammonium nitrate is manufactured by combining ammonia and nitric acid in a reactor. Its primary purpose is for the manufacture of fertilizers. Another major use of NH_4NO_3 is commercial and military explosives; this accounts for 20 percent of the overall use of the chemical. Both fertilizers and explosives are considered vital during the postattack recovery period. The process equipment used in the production of NH_4NO_3 is representative of the types of process equipment found in the solid chemical segment of the 2819 industry (compressors, filters, evaporators, reactors, coolers, absorbers, furnaces, burners, quenchers, liquid gas separators, dryers, crystallizers, centrifuges, and grinders).

- The sulfuric acid industry is considered a basic inorganic chemical industry as it is used in innumerable processes. Twenty-one million

tons of H_2SO_4 were produced in 1963 and accounted for 6.5 percent of sales in the 2819 group. The contact process for sulfuric acid manufacturing is the most commonly used (90 percent of all H_2SO_4 made) and while it is a relatively simple process it is representative of other liquid chemical manufacturing in the 2819 industry.

The 2819 industries below were considered for inclusion in the study but were rejected for the reasons noted.

Commercial and Household Bleaches. Representing 6 percent of the 2819 industry sales, bleaches were considered to be a nonvital item for postattack recovery. Chlorine, the chemical base for most bleaches, is being investigated under the 2812 industries.

Boric Acid. This was not considered an essential postattack chemical.

Hydrochloric Acid. Although a major acid (one million tons produced in 1963), HCl is primarily (80 percent) made as a byproduct of other chemical processes; the process equipment is similar to that used in H_2SO_4 manufacturing.

Phosphoric Acid. A major product of the 2819 industry (2.1 million tons produced in 1963), the main use of phosphoric acid is for fertilizer. However, as the wet process for $H_2P_2O_3$ manufacture uses equipment similar to that of the nitric acid - NH_4NO_3 manufacture, it was excluded from the study.

Aluminum Oxide. Aluminum oxide represents the largest chemical sales (10 percent) for the 2819 industry. The primary use of Al_2O_3 is as an intermediate step between mined bauxite ore and the production of aluminum metal. Aluminum oxide was not considered critical in this study because new aluminum ingots would not be essential in the initial postattack period.

Sodium Salts. None of the various sodium salts (phosphates, silicates, sulfates) was considered critical to the postattack recovery period. Examples of primary uses for sodium salts are sodium phosphate (in detergents) and sodium sulfate (in kraft paper manufacturing).

APPENDIX C

TYPICAL PLANT PROCESSES

APPENDIX C

TYPICAL PLANT PROCESSES

Chlorine and Sodium Hydroxide

A plant that produces 70,000 tons per year of chlorine and 70,000 tons per year of sodium hydroxide was selected and hypothetically designed to represent the 2812 industry (Figure C-1). An electrolytic process utilizing diaphragm cells used by 73 percent of the industry, was chosen as the most representative of the chlorine manufacturing processes.* In this process sodium chloride is mixed with water in saturators (Figure C-1) to form a brine solution which is then purified in clarifiers and filters heated, neutralized with hydrochloric acid, and fed to a diaphragm cell. In the diaphragm cells, electric current (d.c. produced by large rectifiers) is passed through the sodium chloride solution which is decomposed by the current to form a 10 to 12 percent sodium hydroxide solution at the cathode and chlorine gas at the anode. The chlorine gas, which contains a considerable amount of water vapor, is cooled in heat exchangers and then passed through special ceramic drying towers where sulfuric acid is used to dry the chlorine. The dry chlorine gas is then compressed into a liquid, cooled, and stored as liquid chlorine. The sodium hydroxide solution is removed from the bottom of the cell and pumped into multiple effects evaporators with a barometric condensor, producing a 50 percent sodium hydroxide solution. The solution is centrifuged and filtered to remove impurities, then stored or shipped as 50 percent sodium hydroxide.

Liquid Oxygen

The manufacture of oxygen by the modified Linde-Frankel low pressure process was chosen to represent the 2813 industry. The typical oxygen plant, which also produces nitrogen and argon as byproducts, has a production of 33,600 tons per year (Figure C-2). The Linde-Frankel liquifaction process takes incoming air, compresses it in a centrifugal compressor, cools the air, dries it, and sends it into the cold box through reversing heat exchanges. The cold box contains various distillation columns, heat exchangers, and dryers; it is here that the air is cooled

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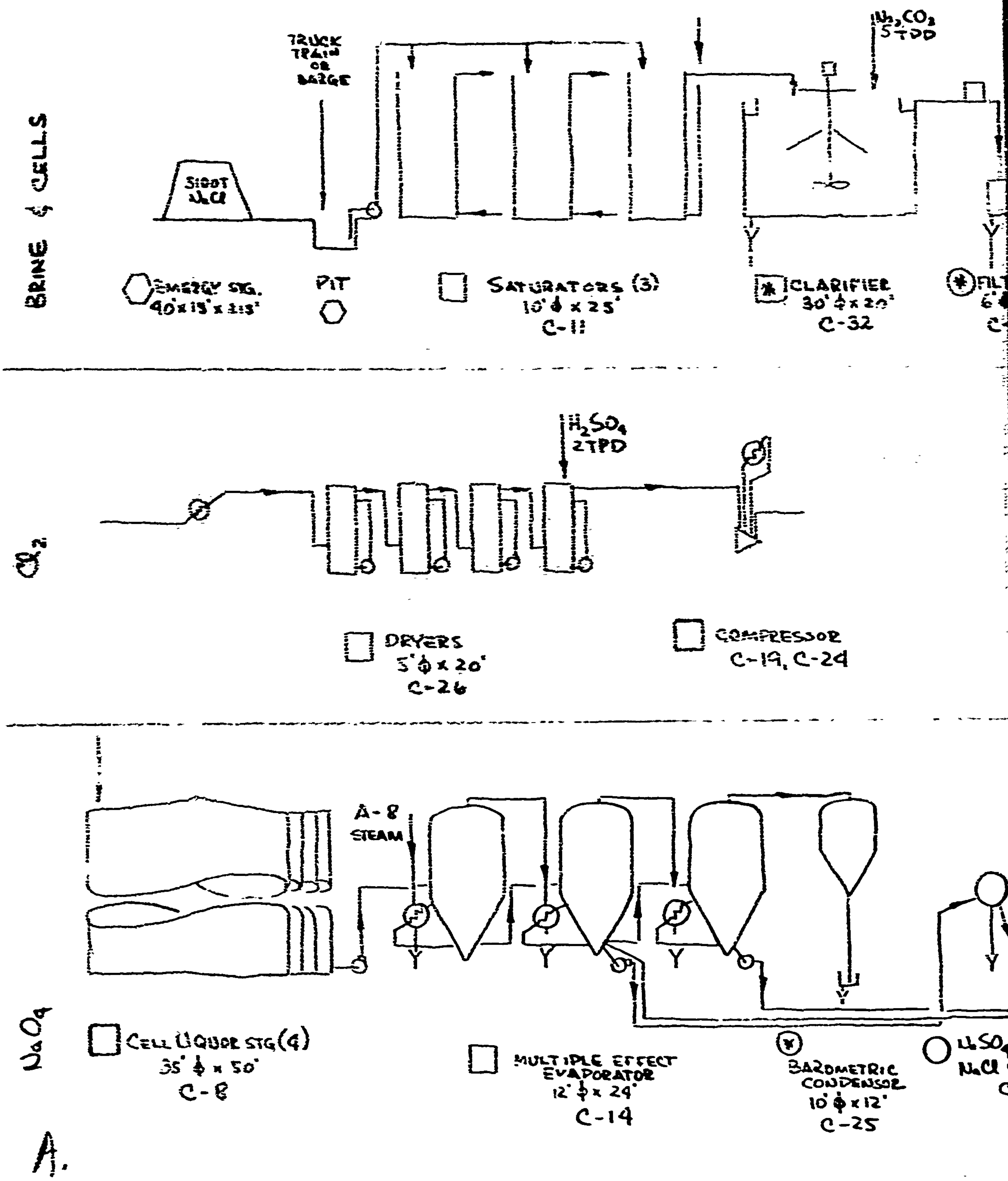
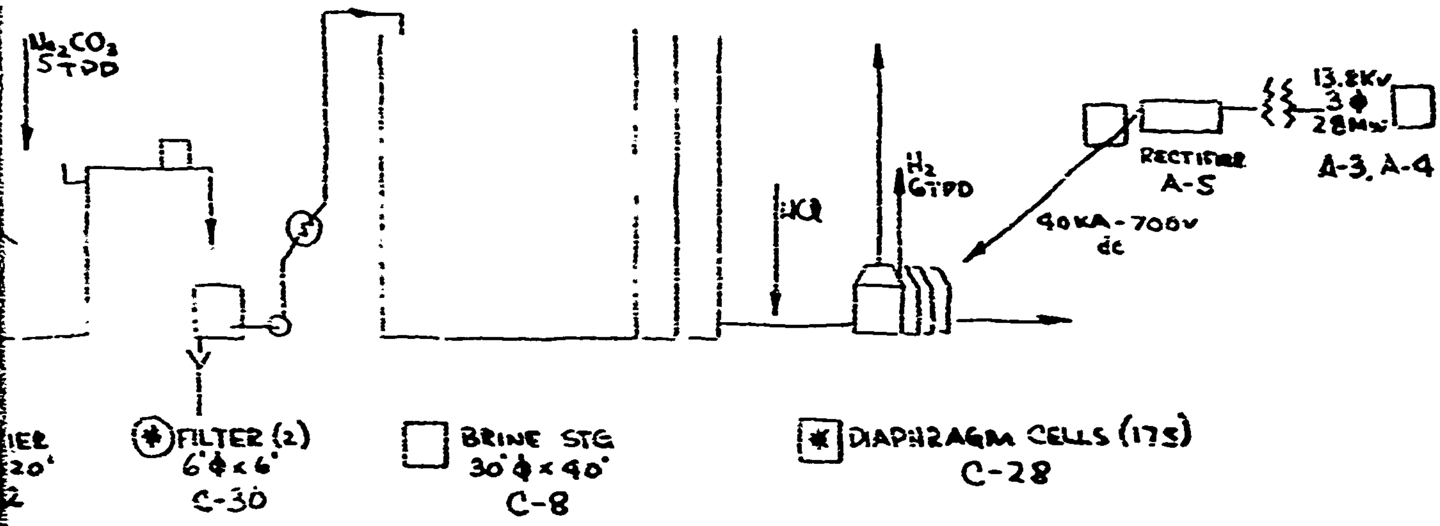
* The mercury cell, which represents 26 percent of the industry, is of growing importance as a source of purified caustic. Structurally the mercury cell (approximately 4' by 40" by 6") reacts very differently from the Hooker cell (Appendix E).

Figure C-1
PROCESS FLOW DIAGRAM, CHLORINE CAUSTIC PLANT

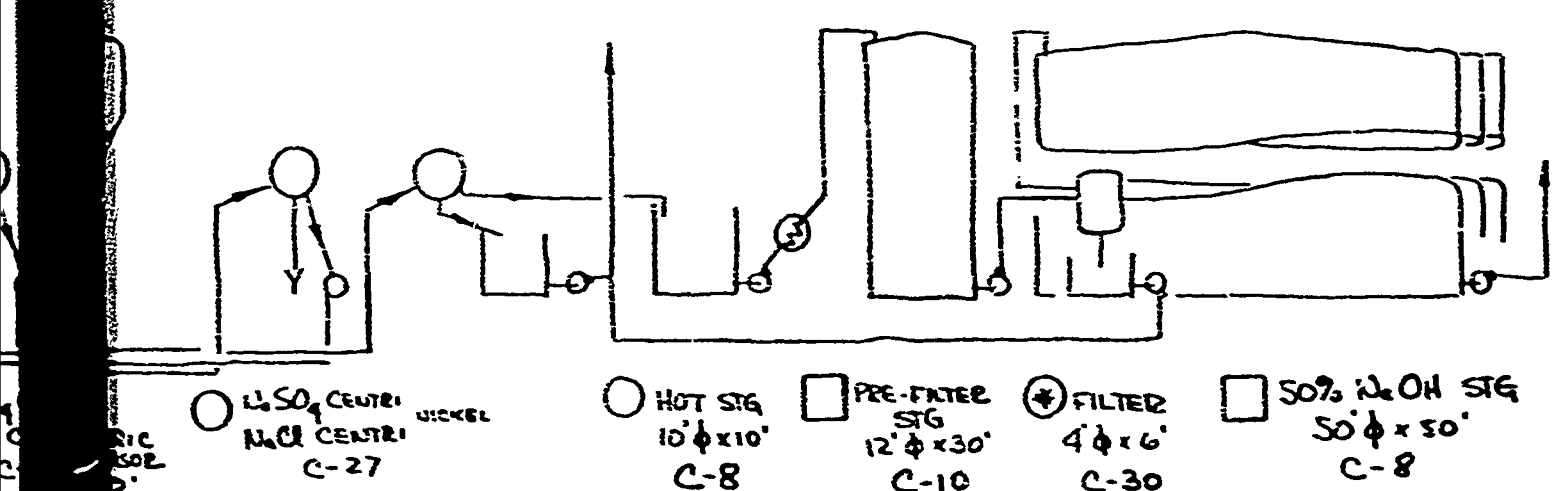




OTHER STRUCTURES:

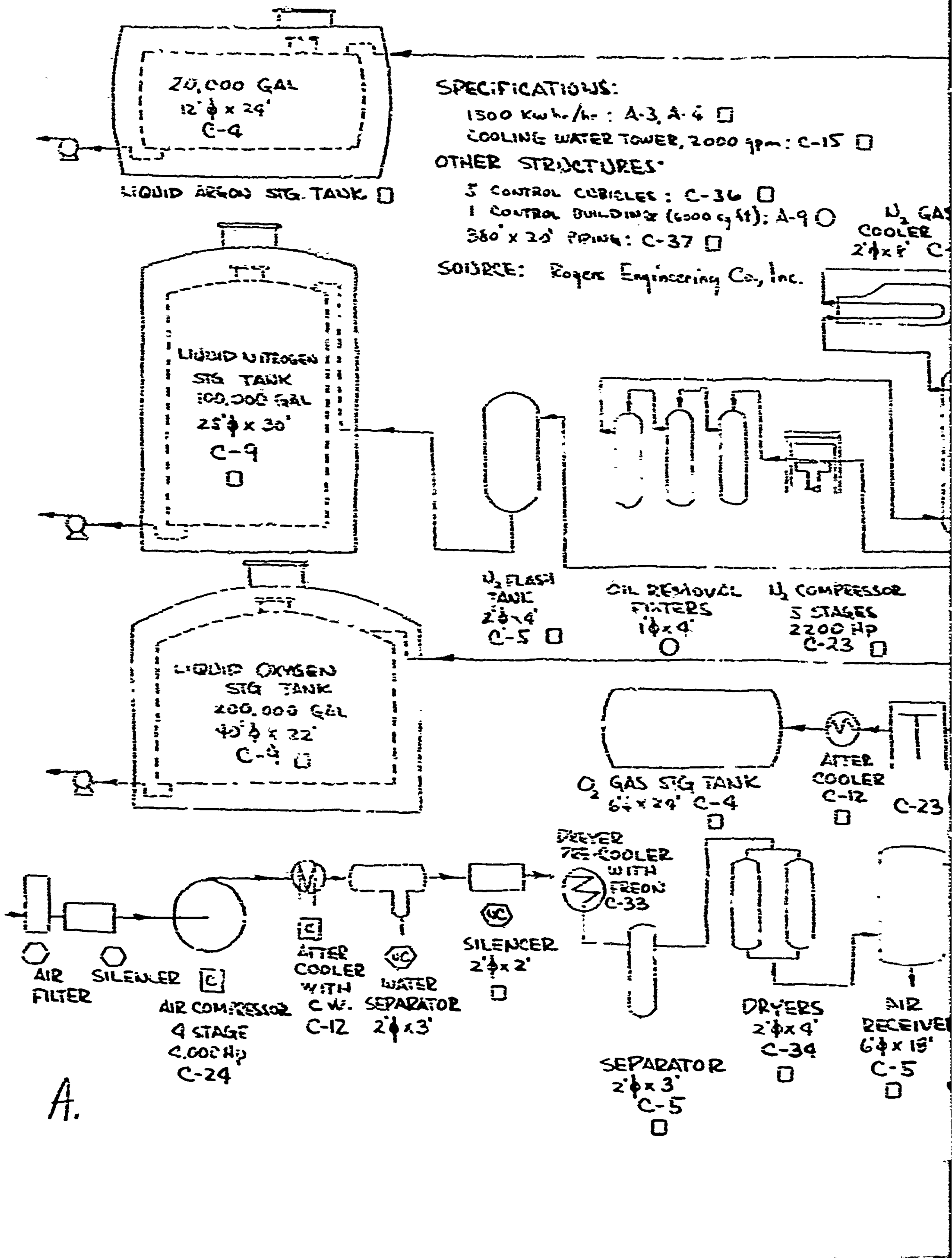
1 CELL BUILDING (30,000 sq ft): A-9
1 CONTROL BUILDING (2,000 sq ft): A-9
3 CELL COOLING TOWERS: C-15
200,000 lbs/hr PACKAGE BOILER: A-8
1150' x 15' PIPING: C-37
8 CONTROL CUBICLES: C-36
HEAT EXCHANGERS: C-12
PUMPS OR DRIVERS: C-18, C-19

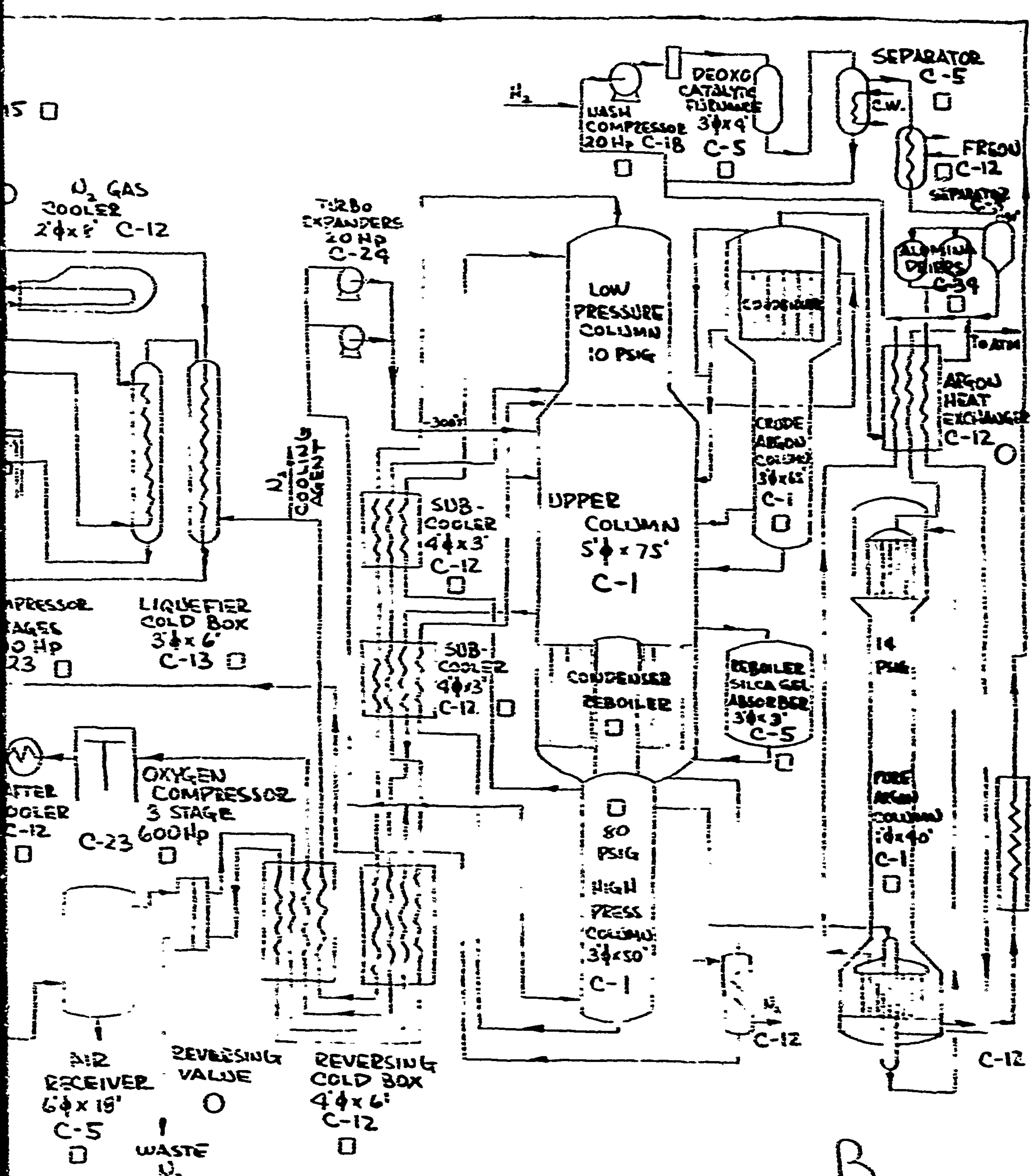
SOURCE: Rogers Engineering Co., Inc.



B

Figure G-2
PROCESS FLOW DIAGRAM, TYPICAL LIQUID AIR PLANT




SEPARATOR C-5
DEOXO CATALYTIC FURNACE 3'φx4' C-5
WASH COMPRESSOR 20 Hp C-18
C.W.
FREON C-12
SEPARATOR
ALUMINA DRIERS C-39
TO ATM
N_2 GAS COOLER 2'φx8' C-12
TURBO EXPANDERS 20 Hp C-24
LOW PRESSURE COLUMN 10 PSIG
UPPER COLUMN 5'φx75' C-1
CRUDE ARGON COLUMN C-1
ARGON HEAT EXCHANGER C-12
N_2 COOLING AGENT
SUB-COOLER 4'φx3' C-12
LIQUEFIER COLD BOX 3'φx6' C-13
CONDENSER REBOILER
REBOILER SILICA GEL ABSORBER 3'φx3' C-5
14 PSIG
PURE ARGON COLUMN C-1
OXYGEN COMPRESSOR 3 STAGE 600 Hp C-23
AFTER COOLER C-12
80 PSIG
HIGH PRESS COLUMN 3'φx50' C-1
C-12
AIR RECEIVER 6'φx15' C-5
REVERSING VALVE
REVERSING COLD BOX 4'φx6' C-12
WASTE N_2

B,

to a liquid and fractionated into oxygen, nitrogen, and other components. The oxygen and nitrogen are then drawn separately from the column as gases and sent through either an oxygen compressor or nitrogen compressor, reliquified and stored as either liquid oxygen or liquid nitrogen.

Ethylene

The manufacture of ethylene from refinery gas was chosen as the process to represent the 2818 industry. The typical ethylene plant used in this study has an annual production of 232,000 tons (Figure C-3). In the ethylene process, refinery gas is initially compressed in centrifical compressors, passed through a caustic scrubber and an acetylene hydrogenation unit to remove impurities, cooled, passed through alumina, dehydrated (which lowers the dew point), and then partially liquified by further cooling before being sent through a series of fractionating columns. Typically, three distillation columns are used. The first removes methane, the second separates ethane and ethylene from the remaining gases, and the third splits the ethylene from the ethane. The ethane is taken off at the bottom of the column, passed through cracking heaters, and put back into the cycle. The ethylene is removed from the top of the column and either stored or shipped as as product.

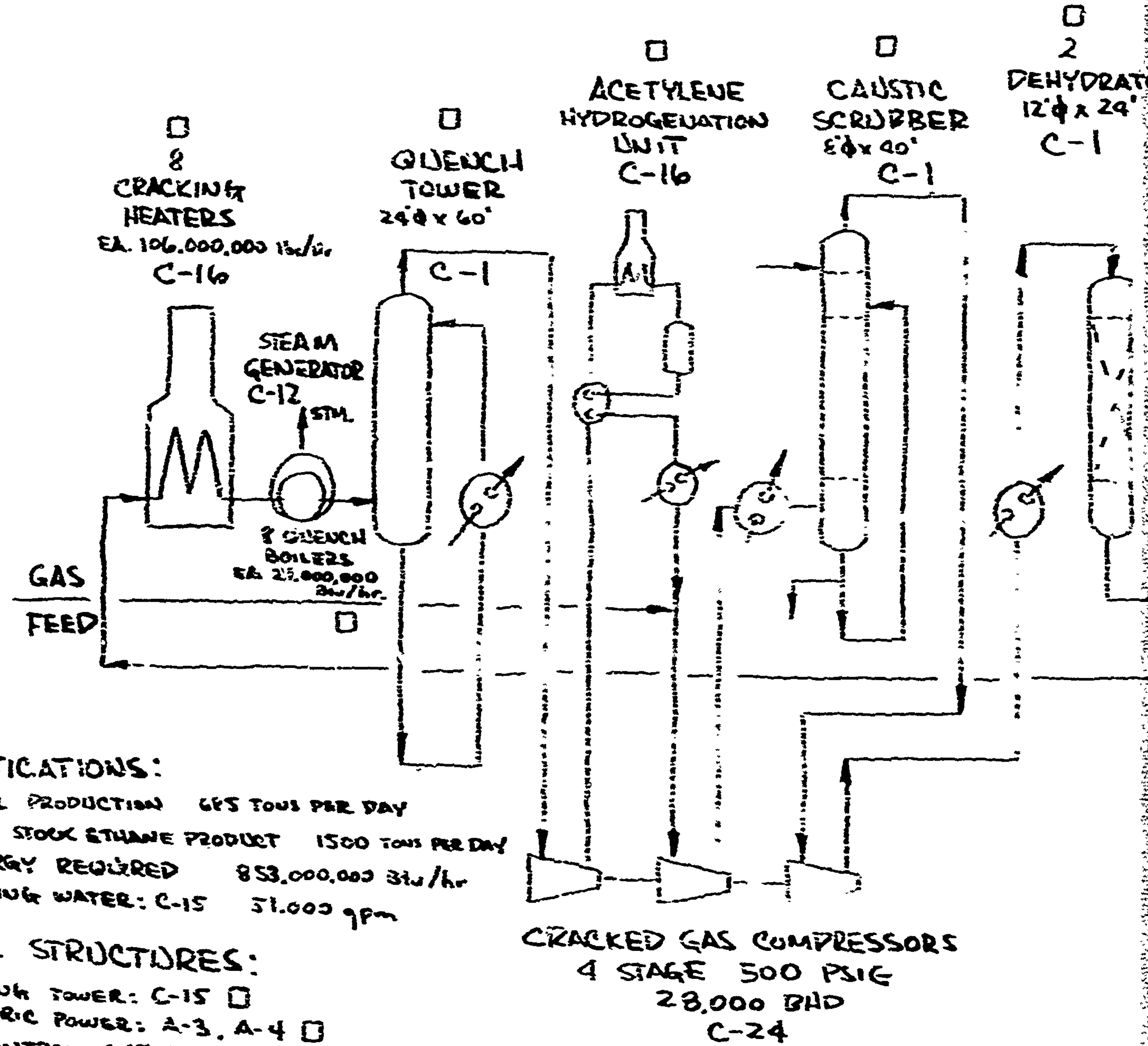
Ammonium Nitrate

The manufacture of ammonium nitrate from ammonia and nitric acid was selected as the process to represent the solid chemical portion of the 2819 industry. The ammonium nitrate plant used in this study has an annual production of 78,200 tons (Figure C-4). In the typical ammonium nitrate plant process (prilling process), ammonia vapor and nitric acid are reacted in stainless steel neutralizing vessels under agitation to form ammonium nitrate. The neutral solution is then pumped through evaporators, concentrated to approximately 95 percent, and pumped through the top of a prilling tower. In the prilling tower, the nitrate solution is discharged through a spray head and falls countercurrent to a stream of conditioned air. As it is falling, the material solidifies into small pellets or prills, which are fed to a rotary kiln dryer and then through a coating drum where the prills are coated with a fine clay to minimize caking tendencies. The prills are then shipped or stored as products.

Sulfuric Acid

The manufacture of sulfuric acid by the contact process was chosen to represent the liquid chemical portion of the 2819 industry. The typical sulfuric acid

Figure C-3
PROCESS FLOW DIAGRAM, ETHYLENE PLANT FROM ETHANE



SPECIFICATIONS:

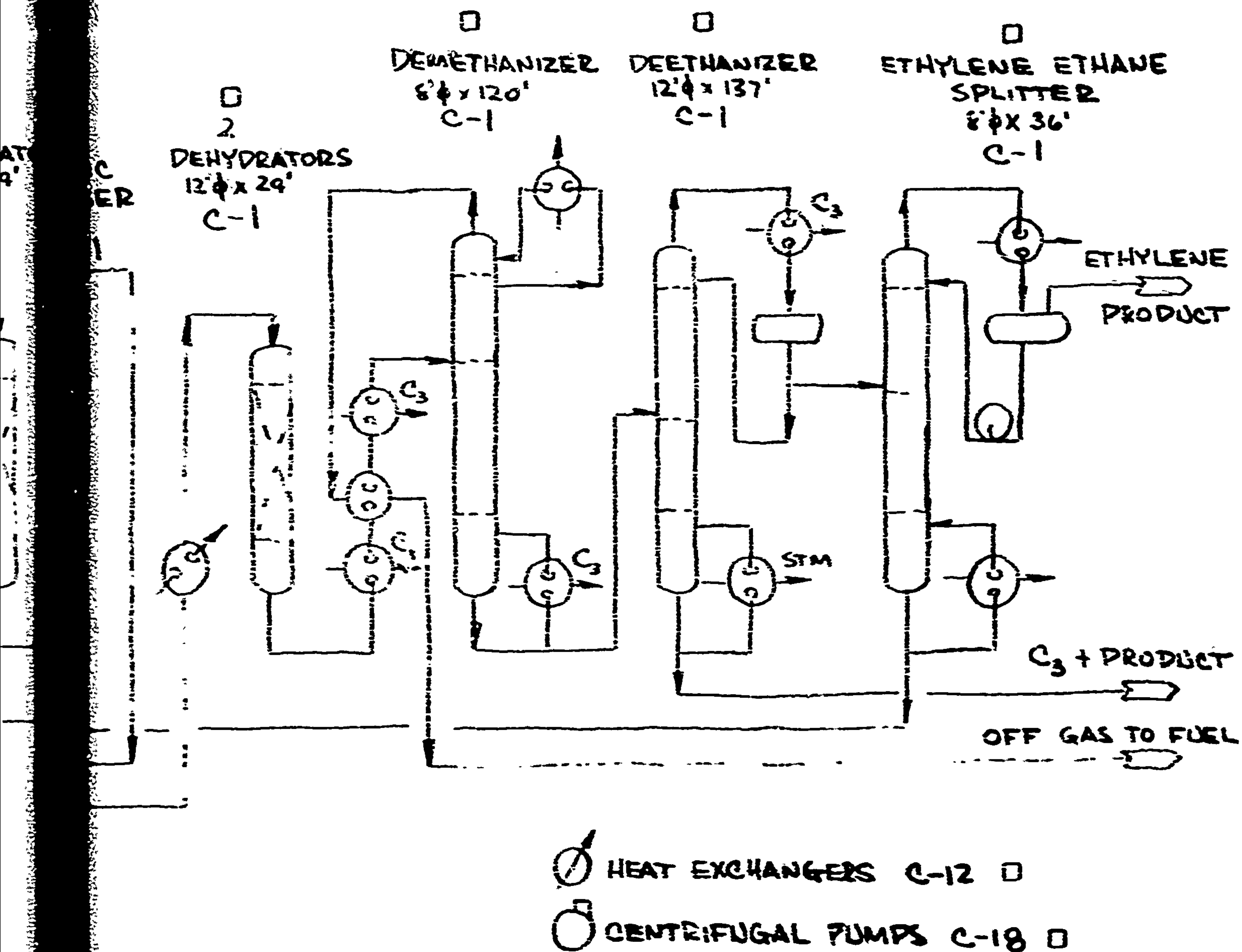
TOTAL PRODUCTION 685 TONS PER DAY
FEED STOCK ETHANE PRODUCT 1500 TONS PER DAY
ENERGY REQUIRED 853.000.000 Btu/hr
COOLING WATER: C-15 31.000 gpm

OTHER STRUCTURES:

COOLING TOWER: C-15
ELECTRIC POWER: A-3, A-4
10 CONTROL CUBICLES: C-36
1 CONTROL BUILDING (4000 sq ft): A-9
750' x 20' PIPING: C-37

SOURCE: Rogers Engineering Co., Inc.

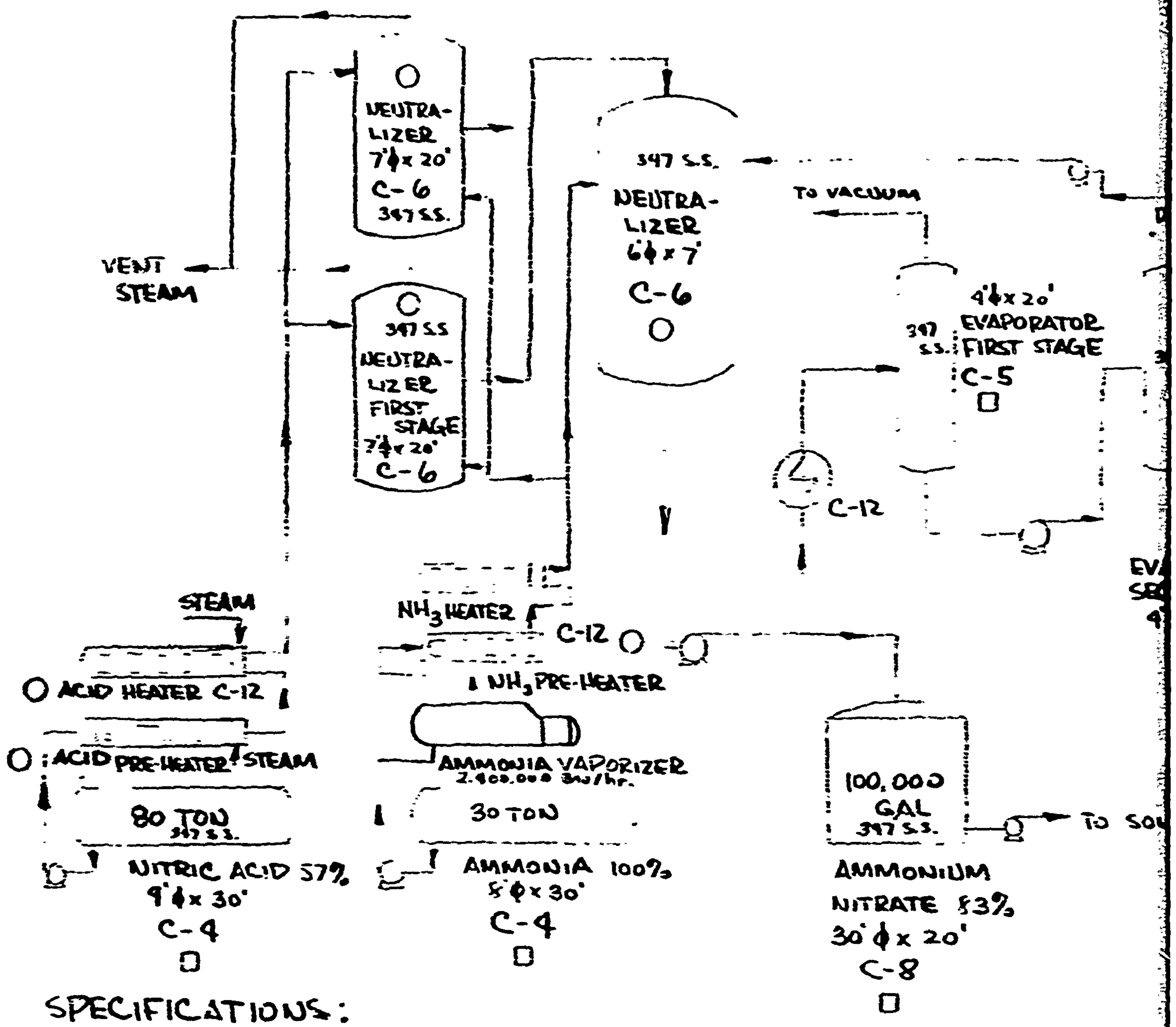
A.



DEMETHANIZER
8'φ x 120'
C-1
DEETHANIZER
12'φ x 137'
C-1
ETHYLENE ETHANE SPLITTER
8'φ X 36'
C-1
2 DEHYDRATORS
12'φ x 29'
C-1
C3
C1
STM
ETHYLENE PRODUCT
C3 + PRODUCT
OFF GAS TO FUEL
HEAT EXCHANGERS C-12
CENTRIFUGAL PUMPS C-18

B.

Figure C-4
PROCESS FLOW DIAGRAM, TYPICAL AMMONIUM NITRATE PLANT



SPECIFICATIONS:

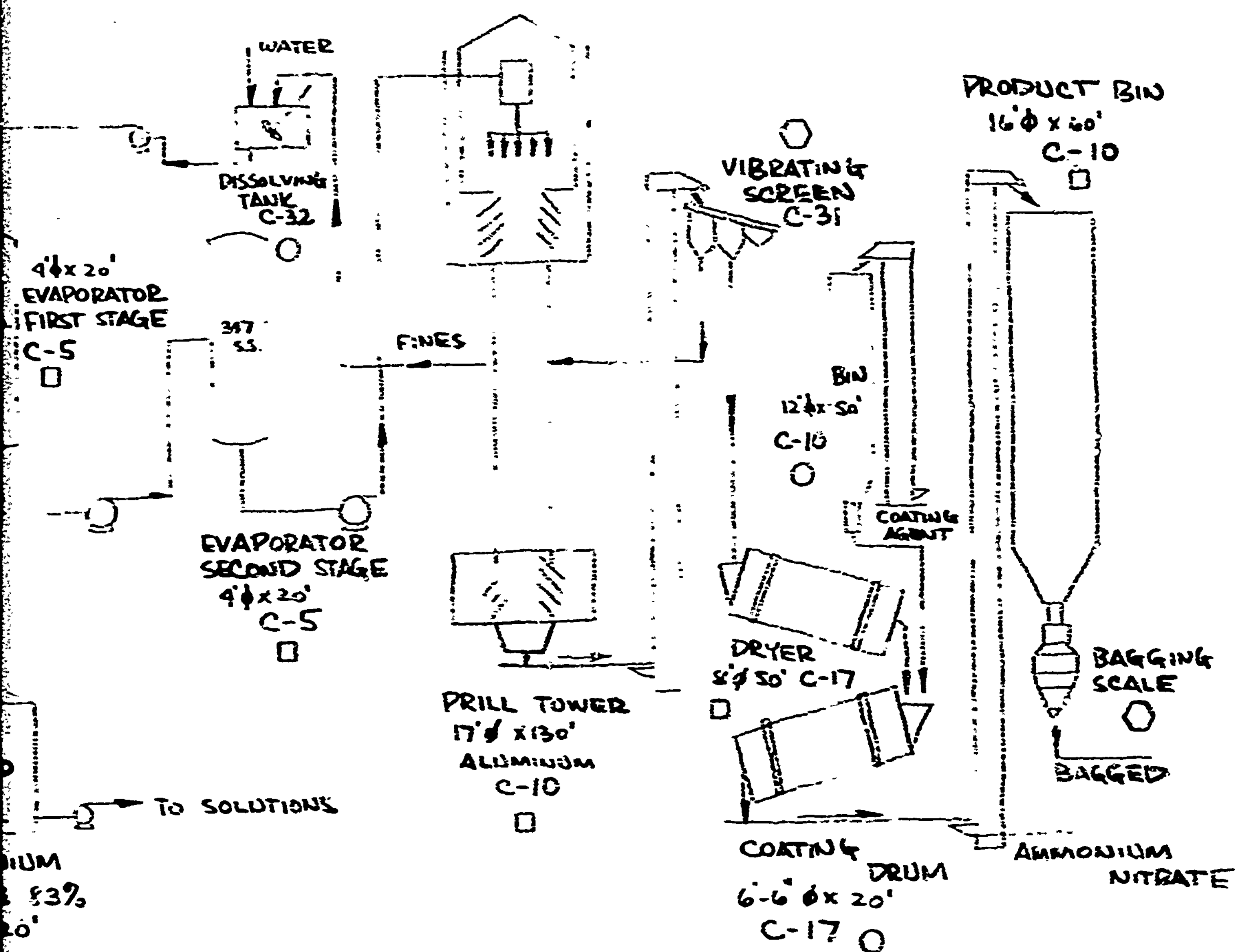
STEAM (200 PSIG) 6000 lbs/hr
STEAM (50 PSIG), PACKAGE BOILER: A-3 9000 lbs/hr
COOLING WATER (25-ΔT): C-15 500 gpm
ELECTRIC POWER: A-3, A-4 350 kw hr/hr

OTHER STRUCTURES:

4 CONTROL CUBICLES: C-36
1 CONTROL BUILDING (7000 sq ft): A-9
120' x 15' PIPING: C-37

SOURCE: Rogers Engi

A.

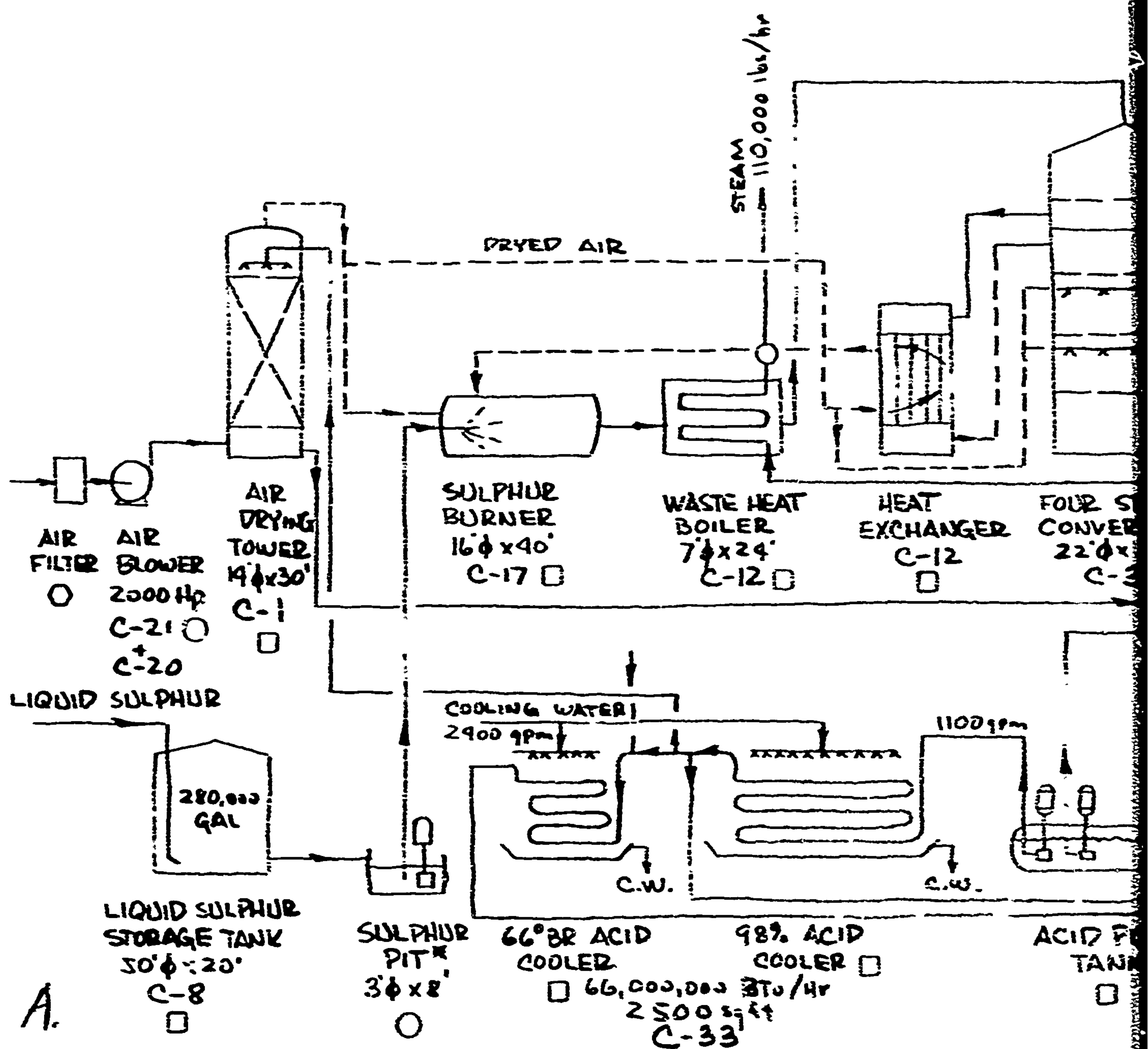


Rogers Engineering Co., Inc

B.

plant (Figure C-5) used in this study has an annual production of 300,000 tons. The contact process using raw sulfur as an input, pumps incoming air through a drying tower, and mixes this with liquid sulfur in a sulfur burner in which sulfur dioxide is produced. The sulfur dioxide mixture is passed through a heat exchanger and then into a converter containing a platinum or vanadium pentoxide catalyst; the sulfur dioxide is converted to approximately 95 percent sulfur trioxide gas. This gas is then partially cooled in a heat exchanger and sent to an oleum tower where oleum is formed. The gas remaining is passed into an acid absorption tower where a slightly higher acid strength is yielded. The acids are then cooled in acid coolers, sent to storage or shipped as product.

Figure C-5
PROCESS FLOW DIAGRAM, TYPICAL CONTACT SULFURIC ACID PLANT



SPECIFICATIONS:

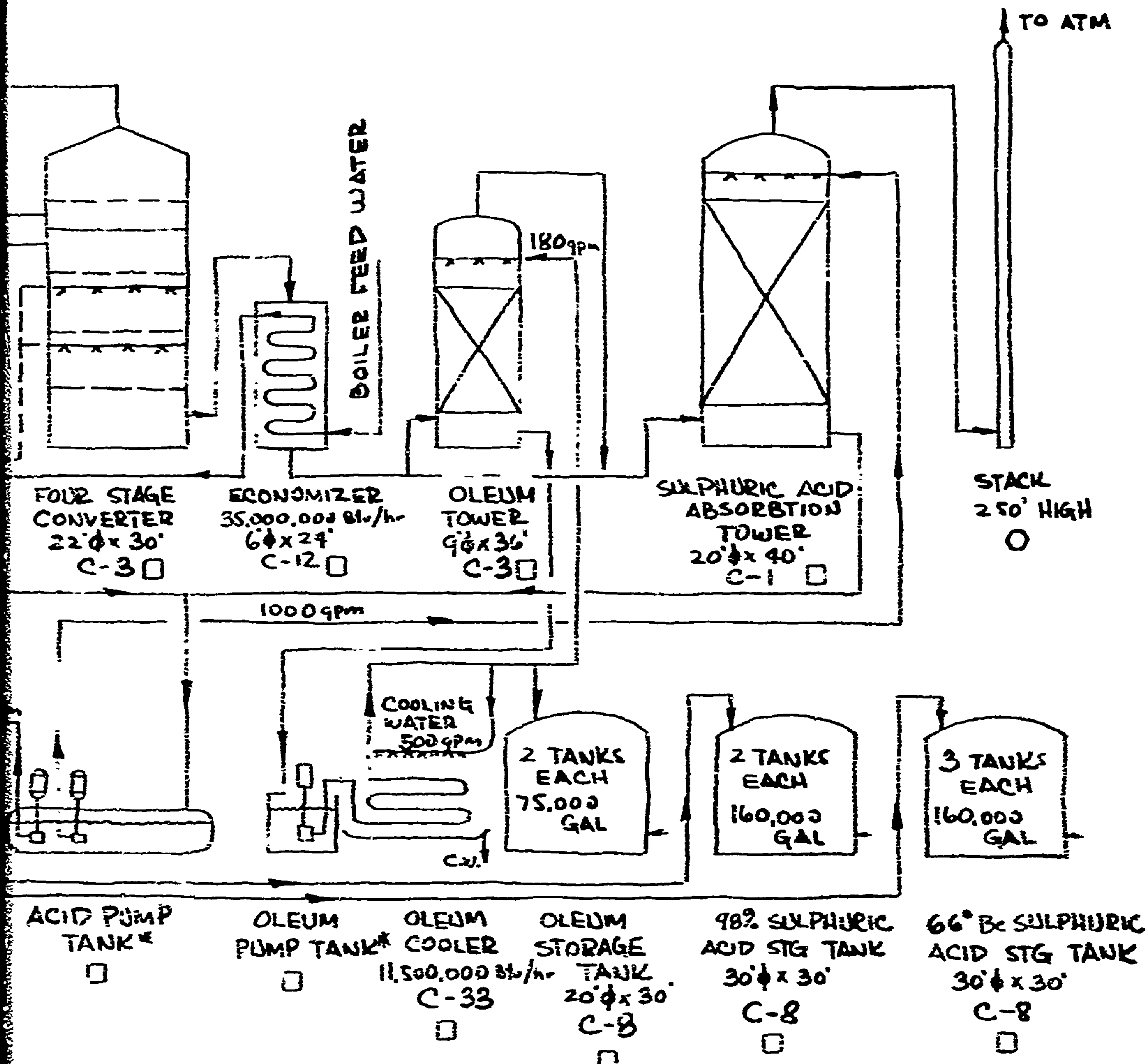
ELECTRIC POWER 200-400 Kw-h/hr
WATER FOR BOILER 250 GPM
WATER FOR ACID PROCESSING 30 GPM
COOLING WATER: C-15 33,000 GPM
AVAILABLE STEAM AFTER PLANT USE 40,000-120,000 lbs/Hr.

* EQUIPMENT ALLO

OTHER STRUCTURES:

CONTROL CUBICLES: C-36
1 CONTROL BUILDING (3,000 sq ft): A-9
560' x 15' PIPING: C-37

SOURCE: Rogers Engineering Co., Inc.



...T ALLOCATED UNDERGROUND

B.

APPENDIX D

AN APPROACH TO STRUCTURAL FAILURE PREDICTION

APPENDIX D

AN APPROACH TO STRUCTURAL FAILURE PREDICTION

Prediction Bases

The fundamental problem in failure prediction is the translation of design criterion and procedure into a reasonable failure criterion and procedure. Basically, all structures are designed to function safely under normal usage, plus survive a reasonable amount of "natural" abuse (high winds, snow, overload). The usual approach in the design situation is to establish the "normal" operating and/or service loads based on considerations such as location and usage (for example, a 70 mph wind and a 100 psf floor load). A safety factor for the possible eventual abuses is then applied. General safety factors have been established through experience and satisfactory performance of structures by government agencies, and research institutes.

In establishing a failure criterion, the safety factor must be removed from structures. The particular problem faced by this study is the desire to make "general" failure predictions for entire industries rather than for individual structural elements or even individual structures. A safety factor of 2.0 was considered reasonable for all structural members. For steel building, the American Institute of Steel Construction (AISC) recommends a safety factor of 1.67 for tension and flexure and a range of 1.67 to 1.92 for stability or buckling problems. Due to the so-called "hidden" safety factor of plastic behavior of structural steel, the average true safety factor for structural steel elements is about 1.85. The American Concrete Institute (ACI) recommends about 2.2 for flexural failures and about 2.5 for compression or buckling failures. While individual organizations, agencies, and firms may use different safety factors, these generally are higher because of particular experiences and uses. For example, the American Society of State Highway Officials (ASSHO) and the American Society of Railway Engineers (ASRRE) both use safety factors of 2.0 or slightly more for steel construction because of the possibility of overload, fatigue, and vibrations.

The next aspect of a broad general failure prediction is the statistical behavior of actual failures. Structural strength (hence, failure) predicted from design information with the safety factor removed is a lower bound failure because design allowables are based on minimum properites, or about a one percent probability of failure. To make other estimates—such as at 50 percent or 99

percent--probability distribution is needed. Here, again, it is necessary to use average distribution(s) for a broad class of failures. Figure D-1 represents a composite of findings of the references listed at the end of this Appendix, and is by no means a precise probability statement. However, it is felt that it gives a reasonable survey of the statistical nature of the problem. One may interpret Figure D-1 as follows: suppose we predict a column failure (buckling) at 100 kips; this means that one percent of similar columns would fail at 100 kips* or less. From Figure D-1 we see a 1.25 strength factor opposite 50 percent and 1.5 opposite 99 percent; it may be interpreted that 50 percent of these columns will fail at 125 kips or less and 99 percent will fail at 150 kips or less. Similar statements for failure can be made about beams (flexure), ceramic parts (brittle fracture), and other segments.

The Prediction Method

A structure is designed for a set of service loads that can be functionally described by setting the structural resistance "R" equal to a function of load:

$$R = f(V_D + V_L + H_D + H_L + \ldots)$$

where V_D is Vertical dead load

V_L is Vertical live load

H_D is Horizontal dead load

H_L is Horizontal live load

It follows then that the failure Resistance R_F can be shown as:

$$R_F = S_f n\, f(V_D + V_L + H_D + H_L + \ldots)$$

where S_f is the statistical strength factor, and

n is the safety factor (2 in this study)

It is understood that the sum notation in the functional relationship is illustrative, meaning the summation of effects and not numbers. One of the interesting aspects of this type of design philosophy is that it is intended to yield a uniform safety factor to a structure; that is, if all loads on the structure are increased by $S_f n$ the structure will fail with a corresponding probability of failure. However, if only one load component is increased, the failure will not be $S_f n$ for the

* kips = 1,000 lbs

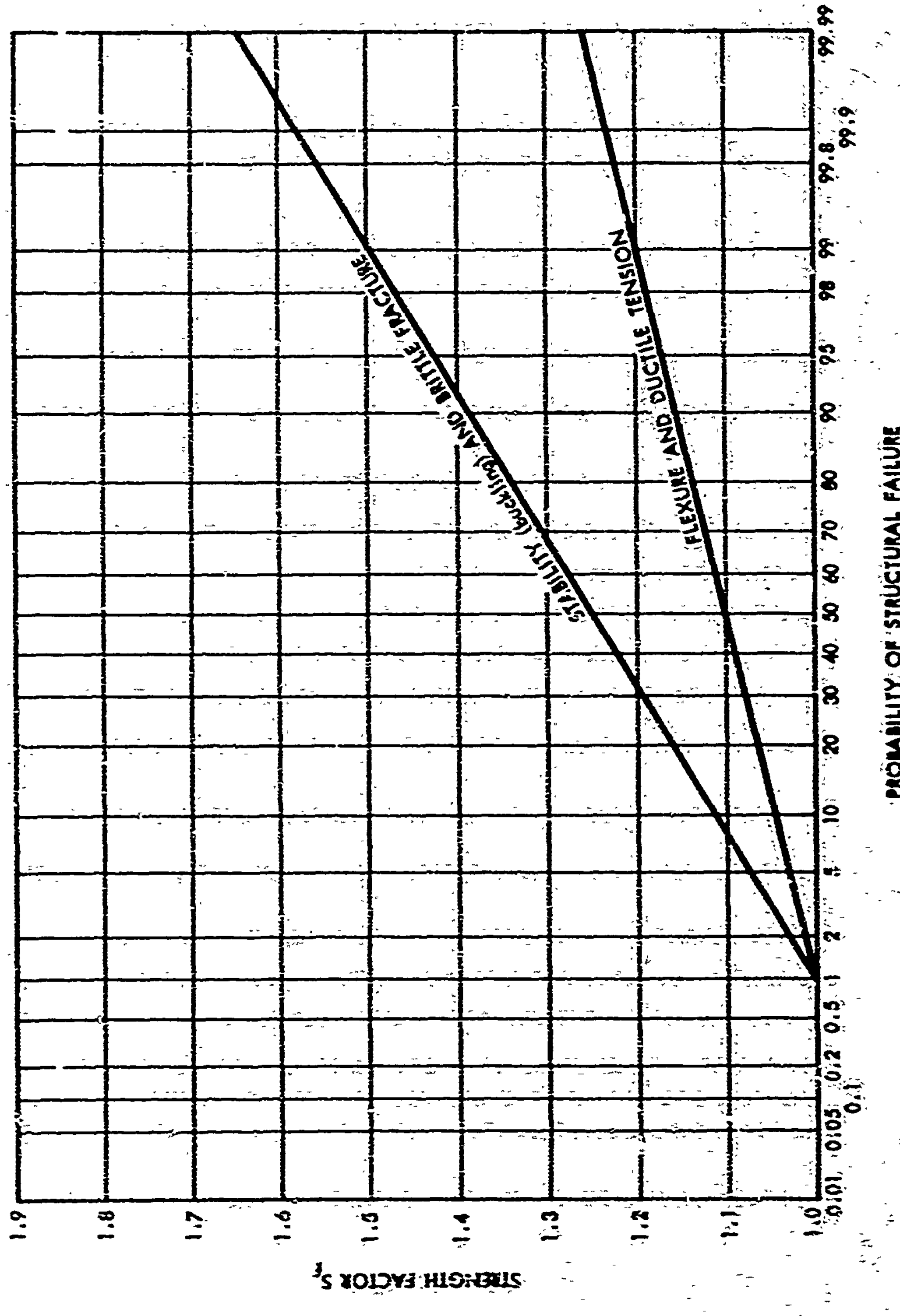
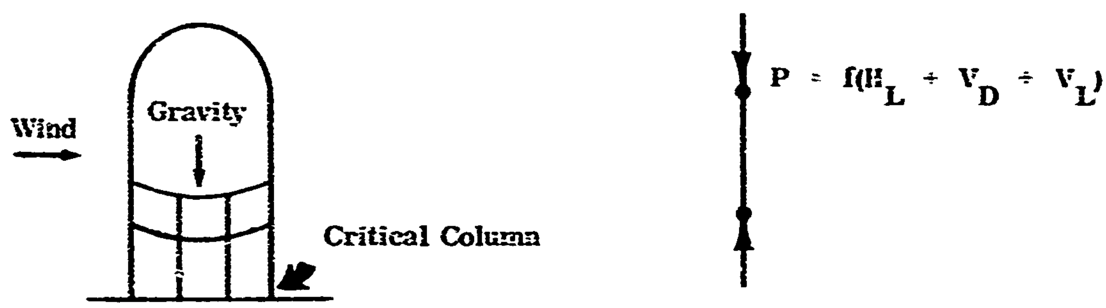


Figure D-1

PROBABILITY OF STRUCTURAL FAILURE AS A FUNCTION OF THE STRENGTH FACTOR

corresponding probability. For example, let us consider a tank type of structure that is supported on a ring of columns which is common for this type of industry. Assume it is a high pressure tank and the columns are the weak link from external perturbations such as a nuclear explosion. The design of these columns would have been controlled by the vertical gravity loads (V_D and V_L) and a horizontal load (H_L) from wind of 100 MPH



We must assume the vertical loads are small (gas filled tank) compared to the wind load, let:

$$P = H_L + (V_D + V_L)$$

$$P = 100 + 50 = 150$$

then: $P_f = S_f n(150)$

or for 50 percent probability of failure

$$P_f = 1.25(2)\ 150$$

$$P_f = 375$$

Note, now that $P_f = S_f n = 2.5$ time the design loads, or if both the vertical and horizontal loads are increased by 2.5, the tank will fail 50 percent of the time when $V_D + V_L = 125$ and $H_L = 250$. Since wind force increase at velocity squared this means a wind velocity of $\sqrt{2.5}\ 100 = 158$ MPH a high and rare wind. However, if only H_L is increased, as would normally happen in a nuclear explosion on a "drag" structure, that means

$H_L + 50 = 375$ would cause failure 50 percent of the time; which is 3.25 times the design wind load which corresponds to 180 MPH, that is we get an increase of 3.25 instead of the previous 2.5.

Another problem one could pose is H_L and $(V_D + V_L)$ reversed in the above problem; such would occur in a tank designed to hold a heavy load. For this case let

$$P = V_D + V_L + H_L$$

$$P = 100 + 50$$

Then at 50 percent probability of failure

$$P_f = 1.25(2)(150) = 375$$

as before. However, if we again only increase the wind we have

$$375 = H_L + 100$$

$$\text{or } H_L = 275$$

which represents a 5.5 increase in the failure load or a wind of 235 MPH.

From the foregoing, it is seen that the actual failure strength of a structural system is highly dependent not only on the loading mechanism (the type of imposed load and/or loads) but on the inherent characteristics of the structure (dead load to live load ratio) and, to a lesser extent, the mode (flexure or buckling).

This brief discussion may explain the large discrepancies in the failure resistances of structures designed with the same factor of safety.

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APPENDIX E

DAMAGE/REPAIR CATALOG

UNIT: Distillation Column

DESCRIPTION: 88 ft high by 4 ft in diameter, 1100 ft^3; six 4-in. pipe connections; three 10-in. pipe connections (light gauge); base, twelve 2-in. anchor bolts

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
							CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
		1%	50%	99%						
Upper half of column's external piping breaks at ground connections due to deflection of column	Drag	6.0	6.8	7.2	35	4	Crane Oxy-acety cutting outfits Rigging gear Welders	Pipe Miscellaneous flanges Gaskets	4 Riggers 2 Equipment operators 1 Millwright 2 Pipe fitters 1 Ironworker 2 Certified welders	Column unusable
Anchor bolts begin yielding, causing slight shifting of column	Drag	8.0	8.8	9.0	60	4	Crane Oxy-acety cutting outfits Rigging gear Welders Truck Compressor Concrete breakers	Pipe Miscellaneous flanges Gaskets Concrete Form lumber Bolt stock	4 Riggers 2 Equipment operators 1 Millwright 2 Pipe fitters 1 Ironworker 2 Certified welders 3 Carpenters 2 Laborers 1 Truck driver	
Distillation column overturns due to failure of anchor bolts; all connections are severed and internal trays disarranged	Drag	9.0	10.0	11.0	277	28	Crane Oxy-acety cutting outfits Welders Truck Compressor Clay spades Back hoe Rigging gear	Valves-gauges Pipe-flanges-fittings Rolled plate Concrete Form lumber Reinforcing bar Bolt stock Insulation Miscellaneous structural steel	4 Riggers 3 Equipment operators 1 Millwright 4 Pipe fitters 2 Certified welders 4 Laborers 2 Ironworkers 2 Welders 2 Ironworkers bar 2 Carpenters 1 Equipment operator 1 Cement finisher 1 Truck driver	

C-2 UNIT: Liquid Extraction Column

DESCRIPTION: 88 ft high by 4 ft in diameter, 1100 ft^3; six 4-in. pipe connections; three 10-in. pipe connections (light gauge); Bare, twelve 2-in. anchor bolts. Column is full of liquid.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	90%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
External piping connected to upper half of extraction column breaks at ground connections due to the columns deflection	Drag	6.0	6.0	7.2	35	4	Crane Oxy-acety cutting outfits Rigging gear Welders	Pipe Miscellaneous flanges Gaskets	4 Riggers 2 Equipment operators 1 Millwright 2 Pipe fitters 1 Ironworker 2 Certified welders	Column unstable
Anchor bolts start yielding causing the column to shift slightly on its foundation	Drag	9.0	10.0	11.0	50	4	Crane Oxy-acety cutting outfits Rigging gear Welders Truck Compressor Concrete breakers	Pipe Miscellaneous flanges Gaskets Concrete Form lumber Bolt stock	4 Riggers 2 Equipment operators 1 Millwright 2 Pipe fitters 1 Ironworker 2 Certified welders 2 Carpenters 2 Laborers 1 Truck driver	
Anchor bolts fail and the extraction column overturns severing all external connections and disarranging internal trays	Drag	10.0	11.0	13.0	333	35	Crane Oxy-acety cutting outfits Welders Truck Compressor Clay spades Back hoe Rigging gear	Valves-gauges Pipe-flanges-fittings Rolled plate Concrete Form lumber Reinforcing bar Bolt stock Insulation Miscellaneous structural steel	4 Riggers 2 Equipment operators 1 Millwright 4 Pipe fitters 2 Certified welders 4 Laborers 4 Ironworkers 4 Welders 2 Carpenters 1 Equipment operator 1 Cement finisher 1 Truck driver	

C-3

UNIT: Packed Column

DESCRIPTION: 88 ft high by 4 ft in diameter, 1100 ft^3; six 4-in. pipe connections; three 10-in. pipe connections (light gauge); Base, twelve 2-in. anchor bolts. Column is packed with Loads.

DAMAGE ESTIMATES					REPAIR ESTIMATES						COMMENTS
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED		
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS			
Upper half of column external piping breaks at ground connections due to deflection of column	Drag	6.0	6.3	7.2	35	4	Crane Oxy-acety cutting equip. Welders Rigging gear	Pipe Miscellaneous flanges Gaskets	4 Riggers 2 Crane operators 1 Millwright 1 Ironworker 4 Pipe fitters		
Anchor bolts begin yielding causing slight shifting of column	Drag	8.0	8.8	9.6	85	8	Crane Oxy-acety cutting equip. Welders Rigging gear Truck Compressor Jackhammers	Pipe Miscellaneous flanges Gaskets Concrete Form lumber Bolt stock	4 Riggers 2 Crane operators 1 Millwright 1 Ironworker 4 Pipe fitters 2 Carpenters 3 Laborers 1 Truck driver		
Distillation column overturns due to failure of anchor bolts, all connections are severed and internal trays disarranged	Drag	9.0	10.0	11.0	217	20	Crane Oxy-acety cutting equip. Welders Rigging gear Truck Compressor Jackhammers Back hoe Gray spades	Pipe Miscellaneous flanges Gaskets Concrete Form lumber Bolt stock Valves-gauges Rolled plate Re-bar Insulation Miscellaneous structural steel	4 Riggers 2 Crane operators 1 Millwright 5 Ironworker 6 Pipe fitters 2 Carpenters 4 Laborers 1 Truck driver 1 Equipment operator 1 Cement finisher		

C-4

UNIT: Horizontal Cylindrical Pressure Vessel

DESCRIPTION: 30-in. diameter, 30 ft long, 1/2-in. R, 1 M.H.-18-in.; six 3-in. pipe connections; level gauge (tubes) drain and fill valves 1/2 full of liquid.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	90%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Glass lining is shattered allowing tank contents to attack metal shell	Diff.	2.0	3.0	4.0	11	6	Welders Heating torches Angle grinder and buffer Cutting torch Ventilation blower Respirator	Granulated and powdered glass Gauge glass Rolled plate	2 Ironworkers 1 Welder 1 Porcelain worker 1 Pipe fitter	Applies to a glass lined vessel
The two leeward supporting columns begin buckling causing the shearing of the various external piping connections to the vessel	Drag	5.0	6.0	7.0	(For glass lined vessel) 20 (For unlined vessel) 15	9 4	Welders Heating torches Angle grinder and buffer Cutting torch Ventilation blower Respirator	Granulated and powdered glass Gauge glass Rolled plate Structural members Pipe and fittings	2 Ironworkers 1 Welder 1 Porcelain worker 1 Pipe fitter 2 Equipment operators	For horizontal vessels mounted 6 ft above ground on columns
Vessel overturns due to failure of supporting columns	Drag	8.0	9.0	10.0	(For glass lined vessel) 34 (For unlined vessel) 20	13 8	Welders Heating torches Angle grinder and buffer Cutting torch Ventilation blower Respirator	Granulated and powdered glass Gauge glass Rolled plate Structural members Pipe and fittings	2 Ironworkers 1 Welder 1 Porcelain worker 1 Pipe fitter 2 Equipment operators	For horizontal vessels mounted 6 ft above ground on columns

C-4 **UNIT:** Horizontal Cylindrical Pressure Vessel (continued)

DESCRIPTION:

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	90%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Anchor bolts fail causing the vessel to shift on its supports and severing external pipe connections	Drag	15.0	16.5	18.0	22	7	Compressor Concrete drill Cutting torch Welder Rigging equipment Crane	Pipe-flanges-fittings Miscellaneous structural material Bolt stock	5 Ironworker 2 Equipment operators 2 Pipe fitters 2 Certified welders 1 Welder 1 Laborer	For horizontal vessels mounted close to the ground on low piers
Vessel displaced off its mounting when anchor bolts shear	Drag	18.0	20.0	22.0	20	9	Compressor Jackhammers Cutting torch Welder Rigging equipment Crane Truck	Pipe-flanges-fittings Miscellaneous structural material Bolt stock	5 Ironworkers 1 Welder 2 Equipment operators 2 Pipe fitters 2 Certified welders 3 Laborers 1 Truck driver	For horizontal vessels mounted close to the ground on low piers

C-5 **UNIT:** Vertical Pressure Vessel

DESCRIPTION: 10 ft diameter by 45 ft high, 1/2 in. shell, eight 4-in. nozzles, two 18-in. man holes, drain and r 1 valves.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Anchor bolts begin yielding causing slight shifting of vessel and severing external pipe connections		12.0	13.2	15.0	22	7	Compressor Concrete drill Cutting torch Welder Rigging equipment Crane	Pipe-flanges-fittings Miscellaneous structural materials Bolt stock	4 Ironworkers 2 Equipment operators 2 Pipe fitters 2 Certified welders 2 Welders 1 Laborer	
Anchor bolts fail and vessel overturns		13.0	14.3	16.2	30	9	Compressor Concrete drill Cutting torch Welder Rigging equipment Crane	Pipe-flanges-fittings Miscellaneous structural materials Bolt stock	4 Ironworkers 2 Equipment operators 2 Pipe fitters 5 Certified welders 2 Welders 3 Laborers	

C-8

UNIT: Liquid Phase Reactors with Mixers

DESCRIPTION: 6 ft diameter by 8 ft high, 1/2 in. shell, 154 ft³, four 4-in. pipe legs; 20 HP mixer-steam jacketed; one 18-in. M.H.; one 10-in. mixer hole; ten 3-in. nozzles.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Control gauges smashed and inoperable	Diff. & missiles	2.0	2.2	2.6	1	1		Gauges-temp (2) Press (1) Liquid level (1) Steam trap	1 Pipe fitter	
Glass lining scattered on blast loaded side	Diff. & missiles	2.0	3.0	3.7	13	8	Cutting torch Welder Heating torch	Gauges Rolled plate Pipe Granulated or powdered glass	1 Ironworker 1 Welder 1 Porcelain worker 1 Insulator	For glass lined reactors
Reactor overturns (if empty/ breaking all connections to vessel	Drag	6.0	6.6	7.2	31	12	Cutting torch Welder Crane Rigging gear Heating torch	Gauges Valves for above Rolled plate Pipe-flanges-fittings	2 Equipment operators 2 Ironworkers 2 Welders 2 Pipe fitters 2 Certified welders 1 Porcelain worker 1 Insulator	
Reactor overturns breaking all connections to vessel	Drag	12.0	15.0	18.0	34	14	Cutting torch Welder Crane Rigging gear Heating torch	Gauges Valves for above Rolled plate Pipe-flanges-fittings Mixer unit complete	1 Electrician 2 Ironworkers 2 Welders 2 Pipe fitters 2 Certified welders 1 Porcelain worker 1 Insulator	

G-7

UNIT: Fluidized Bed Reactor

DESCRIPTION: 8 ft diameter by 30 ft high, 570 ft^3 – cyclone separator 4 ft diameter mounted near top of vessel – blower at grade and tied into bottom of reactor by 18-in. diameter pipe – vessel operates at low pressure.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Control gauges smashed and inoperable	Diff.	2.0	2.2	2.4	1	1		Gauges	1 Pipe fitter	
Cyclone separator overturns rupturing connections to reactor vessel	Drag	3.0	3.75	4.5	9	4	Crane Cutting torch Welder	Flat plate Structural shapes	1 Pipe fitter 2 Ironworkers 1 Welder 2 Equipment operators	
Blower displaced off mounting and deformed, hot air intake pipe to react or vessel sheared	Diff., Drag & missile	6.0	6.6	7.2	13	6	Cutting torch Welder	Blower pipe Flat plate Blower housing	1 Pipe fitter 1 Millwright 3 Ironworkers 2 Welders 2 Equipment operators	
Fluid bed reactor vessel overturns through anchor bolt failure	Drag	8.0	8.8	9.6	24	7	Cutting torch Welder Crane Compressor Concrete breakers	Flat plate Structural shapes Blower pipe Discharge pipe Concrete Anchor bolts Blower housing	1 Millwright 3 Laborers 1 Carpenter 2 Equipment operators 3 Ironworkers 2 Welders 1 Pipe fitter	

C-H

UNIT: Conical Roof Steel Storage Tank

DESCRIPTION: 80 ft diameter by 20 ft high carbon steel, 12,500 ft³, one 18-in. M.H.; three 6-in. nozzles; one vertical ladder-float gage target board.										
DAMAGE ESTIMATES					REPAIR ESTIMATES					
		PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE					RESOURCES REQUIRED			
DAMAGE DESCRIPTION	CAUSE OF FAILURE	1%	50%	99%	MAN-DAYS REQD	TIME REQD (DAYS)	CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS	LABOR SKILLS REQUIRED	COMMENTS
Roof fails at joints to tank and collapses into the tank.	Diff.	0.5	1.0	1.5	137	28	Cutting torch Welder Crane Rigging gear	Plate segments for 1/2 of roof shape Structural shapes	5 Ironworkers 2 Welders 1 Rigger 2 Equipment operators	Floating roofs can withstand much higher overpressures and would only fail at overpressures > 20 psi
Tank uplifted on blast loaded side with bottom rupturing along joint with shell plates; pipe connections to tank break at entrance into shell body	Diff.	1.0	1.5	2.0	27	10	Cutting torch Welder Rigging equipment	Rolled plate Flat plate Pipe-flanges-fittings Gauge board	2 Laborers 4 Ironworkers 4 Ironworker-welders 2 Equipment operators 1 Rigger	Empty tank
Tank uplifted on blast loaded side with bottom rupturing along joint with shell plates; pipe connections to tank break at entrance into shell body	Diff.	4.0	4.4	4.8	27	10	Cutting torch Welder Rigging equipment	Rolled plate Flat plate Pipe-flanges-fittings Gauge board	2 Laborers 4 Ironworkers 4 Ironworker-welders 2 Equipment operators 1 Rigger	Full tank

C-9

UNIT: Spherical Storage Tank

DESCRIPTION: 60 ft diameter, 80,000 ft³, eight 12-in. pipe column legs; 100 No. pressure; 1/2 in. shell M.H.; 8 in. PRV; six 4-in. nozzles; curved stairway.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Wind (or shear) bracing connecting supporting columns fails	Drag	7.0	8.0	9.0	17	5	Cutting torch Welder Rigging equipment	Structural shapes equal to diagonals	4 Riggers 2 Ironworkers 2 Welders	
Column deformation begins causing inlet and outlet piping to break	Drag	12.0	13.0	14.0	52	9	Cutting torch Welder Rigging equipment Crane	Structural shapes for bracing Plate for legs and attachment Pipe for legs Pipe for inlet and outlet Flanges	4 Riggers 2 Ironworkers 2 Welders 2 Equipment operators 2 Pipe fitters 2 Certified welders	Spherical tank is unusable
Supporting columns deform and collapse causing overturning of the tank	Drag	14.0	15.0	16.0	100	24	Cutting torch Welder Rigging equipment 2 Cranes A-frame truck	Structural shapes for bracing Pipe for legs Pipe for inlet and outlet Plate for legs and attachments Spherical curved plate for 1/4 of surface Repair elements for curved stairway Repair elements for platforms & railings Relief valve Shutoff valves Pipe-flanges-fittings	3 Ironworkers 5 Welders 4 Riggers 4 Equipment operators 2 Pipe fitters 2 Certified welders 1 Truck driver	Overpressures given at the left are for a spherical tank that is full. If tank is empty the predicted failures would occur at slightly higher overpressures (10-15 percent)

C-10

UNIT: Cylindrical Storage Tank (solids)

DESCRIPTION: 21 ft diameter by 72 ft high, 16,000 ft^3, 22-3/4 in. A. B.'s, 1/4 in. bolted plates, construction and conveyor loading system.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Roof of tank fails at joints to roof and collapses into tank	Diff.	1.0	1.1	1.2	20	5	Cutting torches Welders Crane rigging, e.g., gear	Plate steel Structural steel	2 Ironworkers 2 Welders 1 Rigger 1 Equipment operator	
Conveyor loading system deformed and connections to tank broken	Diff. Drag	5.0	6.3	7.5	38	6	Cutting torches Welders Crane rigging, e.g., gear	Plate steel Structural steel Replacement conveyor sections	4 Ironworkers 4 Welders 1 Rigger 1 Equipment operator 1 Millwright	
Anchor bolts begin yielding, tank shifted on foundation	Drag	7.0	7.7	8.4	88	10	Cutting torches Welders Crane rigging, e.g., gear Compressor Concrete drill Truck	Plate steel Structural steel Replacement conveyor sections Bolt stock Concrete Form lumber	4 Ironworkers 4 Welders 5 Riggers 3 Equipment operators 2 Millwright 4 Pipe fitters 2 Carpenters 2 Laborers	
Anchor bolts fail, tank overturns causing severe deformation to 25 percent of tank body	Drag	8.0	9.0	10.0	160	17	Cutting torches Welders Crane rigging, e.g., gear Compressor Concrete drill Truck Back hoe	Plate steel Structural steel Replacement conveyor sections Bolt stock Concrete Form lumber Reinforcing bar	8 Ironworkers 8 Welders 5 Riggers 4 Equipment operators 2 Millwright 4 Pipe fitters 2 Carpenters 2 Laborers	

C-11 **UNIT:** Open Storage Tank

DESCRIPTION: 10 ft diameter by 25 ft high, 1,350 ft^3, 3/8 in. welded plate construction

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Tank uplifted on blast loaded side with bottom rupturing 1/3 of circumference along joint with shell plates, inlet and outlet pipe connections break at entrance to tank	Diff.	1.0	1.5	2.0	6	2	Cutting torch Welder Rigging equipment	Rolled plate Flat plate Pipe flanges and fittings	1 Welder 1 Pipe fitter 1 Laborer	
Tank uplifted on blast loaded side with bottom rupturing 1/3 of circumference along joint with shellplates, inlet and outlet pipe connections break at entrance to tank	Diff.	4.0	5.0	6.0	6	2	Cutting torch Welder Rigging equipment	Rolled plate Flat plate Pipe flanges and fittings	1 Welder 1 Pipe fitter 1 Laborer	
Tank overturns, 25 percent of shell severely deformed	Drag	11.0	12.1	13.4	60	7	Cutting torch Welder Rigging equipment	Rolled plate Flat plate Pipe flanges and fittings Bolt stock Reinforcing bar	3 Welders 1 Pipe fitter 2 Laborers 2 Riggers 2 Equipment operators 1 Carpenter 1 Millwright 2 Ironworkers	

C-12 CPHY: Horizontal Heat Exchanger

DESCRIPTION: Each exchanger is 20 ft long by 3 ft diameter, 3/4 in. tubes, 175 tubes enter in shell (4) 6 ft nozzles 150 PSIG design shell and tube sides. Admiralty tubes, steel shell.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Anchor bolts holding exchangers begin yielding and exchangers deflect breaking pipe connections	Drag	7.0	7.7	8.4	10	4	Welding machine Oxy-acetylene torch	Cinch anchors Pipe Flanges	1 Certified welder 1 Welder 1 Laborer 1 Millwright 2 Pipe fitters	Three or more for horizontal heat exchangers mounted in series by stacking one on top of the other
Anchor bolts fail and heat exchangers overturn rupturing all piping and causes some rupture and misalignment of internal tubes	Drag	8.0	8.8	9.6	20	8	Cherry picker Oxy-acetylene torch 1 Welding machine	Structural steel for framework Flanges Plates Tubes Cinch anchors Pipe	1 Equipment operator 2 Riggers 2 Certified welders 1 Welder 2 Boilermakers 2 Millwrights 2 Pipe fitters 1 Laborer	Three or more for horizontal heat exchangers mounted in series by stacking one on top of the other
Inlet and outlet pipes break	Drag & missile	13.0	14.3	15.6	7	4	Welding machine Oxy-acetylene torch		1 Welder 1 Certified welder 2 Pipe fitters	For a single heat exchanger mounted close to the ground on low piers
Heat exchanger displaced off mountings, all piping connections ruptured and some damage and misalignment of internal tubes	Drag & missile	20.0			10	7	Cherry picker Welding machine Oxy-acetylene torch	Flanges Steel plate Tubes Cinch anchors Pipe	1 Equipment operator 2 Riggers 1 Certified welder 1 Welder 1 Boilermaker 1 Millwright 2 Pipe fitters 1 Laborer	For a single heat exchanger mounted close to the ground on low piers

C-13 **UNIT:** Heat exchanger (Vertical)

DESCRIPTION: Exchanger is 20 ft high by 3 ft diameter, 3/4 in. tubes, 175 tubes water in shell (4/6 ft nozzles 150 PSIG design shell and tube sides. Admiralty tubes, steel shell).

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Pipes shear at connection to heat exchanger	Drag & missile	13.0	14.5	16.0	7	4	Welding machine Oxy-acetylene torch		1 Welder 1 Certified welder 2 Pipe fitters	
Heat exchanger displaced off mountings and overturns breaking all connections, slight deformation to heat exchanger shell, internal tubes damaged and displaced	Drag	16.6	20.0	24.0	15	2	Cherry picker Welding machine Oxy-acetylene torch	Flanges Steel plate Tubes Cinch anchors Pipe	1 Equipment operator 2 Riggers 1 Welder 1 Certified welder 1 Boilermaker 1 Millwright 2 Pipe fitters 1 Laborer	Unit inoperable

C-14 UNIT: Multiple Effect Evaporator

DESCRIPTION: 3 effect - 3 shells operate under vacuum with accessory ejectors, 35 ft straight side by 15 ft diameter, 3000 ft^3. External stiffeners - 2" in, vapor outlet, 6 in, make up - two 12-in. nozzles - two 3-in. nozzles, 2-in. block insulation - 12 ft high structural support legs - cone bottom - dome top - gauges (temp., press, level, control).

DAMAGE ESTIMATES					REPAIR ESTIMATES					COMMENTS
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Evaporator overturns breaking all connections and suffers slight deformation of shell	Drag	3.0	3.70	4.5	103	10	Crane Cutting torch Welder Rigging equipment Scaffolding	Rolled plate Flat plate Pipe-flges.-ftgs. Gauges Insulation material	2 Equipment operators 2 Pipe fitters 2 Certified welders 2 Ironworkers 2 Welders 8 Insulators	Unit inoperable, evaporator empty
Monitoring gauges are broken and bent, pneumatic control tubing ruptured	Diff & drag	2.0	2.6	3.0	4	2		Gauges Tubing	2 Pipe fitters	Manual operation required
Leeward supporting columns buckle deforming frame evaporator is still intact	Drag	6.0	7.5	9.0	20	5	Rigging equipment Cutting torch Welder Porta jack equipment Cribbing material	Structural shapes Pipe-flges.-ftgs.	3 Ironworkers 1 Welder 2 Pipe fitters 2 Certified welders	Unit inoperable
Evaporator overturns when leeward supporting columns fail through buckling, 25 percent of shell body severely deformed, all connections to evaporator are ruptured	Drag	8.0	10.0	12.0	104	38	Crane Rigging equipment Cutting torch Welder Porta jack equipment Scaffolding	Structural shapes Pipe-flges.-ftgs. Rolled plate - cone Rolled plate - shell Dished head segment Gauges Insulation material	4 Welders 2 Equipment operators 2 Ironworkers 2 Pipe fitters 2 Certified welders 8 Insulators	
Nickel inlet and outlet feed pipes are crushed and irreparable	Diff.	9.0	11.2	13.5	200	30	Cutting torch Welder Rigging equipment	Nickel pipe Nickel flanges	All of above plus 2 Pipe fitters 2 Certified welders	

C-16

UNIT: Cooling Tower

DESCRIPTION: 3 cells, 20 ft by 20 ft long, widow 18 ft high, 8 in. inlet pipes, (3) 8 ft diameter fans, redwood fill, 800 GPM/cell

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Corrugated asbestos louvers on the break leeward side, shatter and are blown into the interiors of the tower	Diff.	0.5	0.75	1.0	11	6	Scaffolding truck	Corrugated asbestos siding	2 Carpenters 2 Laborers 1 Truck driver	
Twenty-five percent of interior lathwork grid is destroyed	Diff. & missile	1.5	1.8	1.8	23	9		Redwood lath	2 Laborers 2 Carpenters	Cooling tower still usable but at a much reduced efficiency
Fan cylinder shatters causing deformation of fan blades	Diff.	2.0	2.2	2.4	32	10		Fan blades Fan cylinders	3 Millwrights	Fan inoperable
Tower frame fails, collapsing tower body into basin, all external and internal piping is broken, fan blades are severely deformed and drive shaft between motor and fan suffering misalignment. All interior lath and filling destroyed.	Drag	4.0	6.0	8.0	82	21		Redwood lath	1 Truck driver 2 Laborers 2 Carpenters 2 Pipe fitters	

G-18

UNIT: Direct Fired Box Type Heaters

DESCRIPTION: 35 ft wide by 60 ft long, 45,000 ft³, 8 ft aboveground, vertical base wall and pitched roof. 35 ft to base of stack. 8 burners, stack 72 in. in diameter, brick lined floor walls and underside of roof. Base walls 10 ft high, balance of height to roof pitch. Light external framing (e.g., 4 in. 13 1/4 glass walls. 3 in. water tubes racked on inside surfaces of walls and roof. Stack lined with 3 in. sprayed on gunite.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Fire brick lining heater sides is jarred loose and thrown into bottom of furnace damaging burners and tubes	Diff.	1.0	1.5	2.0	240	52	Cutting torch Welder Rigging equipment Tubing rollers	Brick Steel plate 3 in. boiler tubing Studs-clips	4 Boilermakers 4 Certified welders 4 Bricklayers	Heater unusable
Heater frame begins to buckle causing shearing of inlet and outlet connections to heater and deformation of internal tubes	Diff.	1.5	2.0	3.5	250	52	Cutting torch Welder Rigging equipment Tubing rollers 5 Cranes	Brick Steel plate 3 in. boiler tube Studs-clips Structural members	4 Bricklayers 4 Boilermakers 2 Boilermaker helpers 4 Certified welders 4 Laborers 2 Ironworkers 3 Welders 2 Equipment operators 2 Insulators	Overpressure given is for a heater with its long side oriented toward the blast wave. If blast wave orientation was end on failure would occur at approximately 1-1/2 times the overpressure given for side on orientation
Heater frame fails through buckling and furnace overturns	Diff.	3.0	4.0	5.0	370	77	Welder Cutting torch Rigging equipment Tubing rollers 2 Cranes	Brick Steel plate 3 in. boiler tube Studs-clips Structural members	4 Bricklayers 4 Boilermakers 2 Boilermaker helpers 4 Certified welders 4 Laborers 2 Ironworkers 3 Welders 2 Equipment operators 2 Insulators	

C-17 UNIT, Rotary Kiln Dryer

DESCRIPTION: 10 ft diameter by 75 ft long, 40,000 ft^3, 2 tires 1/2 in. plate wall 8 ft high at low end and 15 ft high at high end. Flue housing one end - discharge housing other end. Lined with brick. Direct gear drive through gear reducers. Burner one end. Flue and discharge housings 1/4 in. plate. Discharge housing has "Liner" plates.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Intake duct and flue duct crushed and ruptured	Diff. & drag	5.0	6.0	7.2	30	5	Crane Cutting torch Welder	1/4 plate Structural shapes	2 Equipment operators 2 Ironworkers 2 Welders	
All external connections to kiln are broken	Drag	8.0	8.8	9.0	72	10	Crane Cutting torch	1/4 plate Structural shapes Liner plate Piping for burner	2 Equipment operators 3 Ironworkers 2 Welders 2 Pipe fitters	
Kiln is displaced off mountings, girt gear tooth are broken, some deformation of kiln shell	Drag	10.5	11.0	12.0	204	48	Crane Cutting torch Welder Rigging gear	Spare bullwheel and pinion Fire brick Rolled plate Flat plate Structural shapes Piping	4 Laborers 2 Millwrights 2 Equipment operators 2 Ironworkers 2 Welders 3 Bricklayers 2 Pipe fitters	

C-18 UNIT: Centrifugal Pump

DESCRIPTION: 300 ft TDH, 300 GPM, 4 in. Disch., 6 in. Suct., CI case, CI bowl, 40 hp motor, ASA Std. type.

DAMAGE ESTIMATES					REPAIR ESTIMATES					COMMENTS
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Pump inlet and outlet pipes break	Drag & missile	38.0	13.0	14.0	4	2	Oxy-acetylene torch Welding machine	Pipe gaskets	1 Certified welder 1 Welder 1 Pipe fitter 1 Millwright	
Base plate anchor bolts sheared off, misalignment between pump and prime mover, possible damage to pump casing from missiles, packing seals damaged	Drag & missile	14.0	16.5	18.0	8	5	Crane	Expansion bolts Pump casing grout	1 Pipe fitter 1 Electrician 1 Millwright 1 Laborer 1 Equipment operator 1 Certified welder	Unit inoperable

C-19

UNIT: Integral HP Electric Motor

DESCRIPTION: 1000 hp, 400 rpm, synchronous

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Missile damage motor windings, causing severe short circuits (if damaged when operating)	Missiles & diff.	4.0	5.0	6.0	14	7		Pole pieces Stator coils	2 Electricians 2 Riggers	
Electric power connections to motor are severed, conduit box is deformed	Missiles, diff. & drag	7.0	8.8	11.2	28	7		Conduit box Cable	2 Electricians 2 Riggers	
Anchor bolts shear, motor displaced off mountings, probable damage to motor casing from missiles	Missile, diff. & drag	21.0	20.0	26.0	51	21	Crane Compressor Jack hammer Truck	Pole pieces Stator coils Anchor bolts Grout Motor shaft	3 Electricians 2 Riggers 2 Laborers 1 Equipment operator	

S-20

UNIT: Steam Turbine Drive

DESCRIPTION: Single stage 25 hp, 3600 rpm, 150 psig inlet, 40 psig exhaust, insulated, mechanical governor, ring oiled bearings.

DAMAGE ESTIMATES						REPAIR ESTIMATES				
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Cooling water pipe and drain connections to turbine are severed	Missile & drag	7.0	7.7	8.5	2	1		Pipe & fittings	2 Pipe fitters	Unit inoperable
Governor linkage deformed and governor valve deformed	Missile, drag & diff.	10.0	12.5	15.0	4	2		New linkage and governor valve	1 Millwright	
Steam inlet and outlet pipes to the turbine rupture	Drag & missile	12.0	14.5	16.0	10	4	Oxy-acetylene torch Welding mach.	Pipe	2 Pipe fitters 1 Welder 1 Certified welder 1 Millwright 1 Laborer	
Anchor bolts shear and turbine is displaced off mountings, all external piping connections severed	Drag & missile	20.0	24.0	34.0	10	5	Crane Compressor Jack hammer	Grout Expansion bolts Shim stock Coupling	1 Laborer 2 Riggers 1 Equipment operator 1 Millwright 2 Pipe fitters 1 Certified welder	

C-41

UNIT: Blower

DESCRIPTION: 100 HP, 19,300 CFM centrifugal multivane forward wheel blower.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Buckling of blower casing and separation of outlet	Diff. & drag	4.0	5.0	6.0	5	2	Flame cutting welder	Steel plate Insulation	1 Millwright 1 Pipe fitter 1 Laborer	
Blower crushed, all connections are severed and duct is crushed	Diff. & drag	8.0	10.0	12.0	17	4	Flame cutting welder	Steel plate Insulation Angle iron Ducting Conduit and wire	2 Millwrights 1 Pipe fitter 1 Electrician 1 Laborer	

C-22 UNIT: Steam Jet Ejector and Surface Inter-after Condenser

DESCRIPTION: 2 stage 18 in. diameter by 8 ft long. After condenser-injector and ejector units mounted 3 ft above floor.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Pressure gauge smashed and inoperable	Diff. & missile	2.0	2.2	3.5	1	1		Gauge	1 Pipe fitter	
Steam inlet pipe and condensate outlet pipe break at the connection to the pipe manifold	Drag & missile	12.0	13.2	14.4	2	2		Pipe-flanges	1 Pipe fitter 1 Insulator	Unit inoperable
Unit displaced off of foundation and overturns when anchor bolts fail, all external piping connections are severed and ejectors integral piping suffers some deformation	Diff., drag & missile	14.0	17.5	21.0	10	6	Rigging equipment	Pipe-flanges-fittings Bolts Insulation Ejector parts	2 Pipe fitters 1 Insulator	

C-23

UNIT: Reciprocating Compressor

DESCRIPTION: 1000 hp, 450 rpm, balanced opposed 2-stage air comp., 4 cylinders

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Small control piping ruptured, indicating gauges smashed and inoperable	Missile, drag & diff.	2.0	3.0	4.0	4	2		Pipe, tubing pressure gauges temp. indicators	2 Pipe fitters	Manual operation required
Deformation of external piping with numerous breaks and ruptures occurring	Diff., drag & missile	13.0	14.0	16.0	18	5		Pipe	2 Pipe fitters 1 Certified welder 1 Welder 2 Riggers 2 Laborers	
Misalignment between compressor and motor	Diff. & drag	20.0	22.0	24.0	32	12	Crane	Motor shaft Motor Compressor bearings	2 Millwrights 2 Riggers 1 Equipment operator 2 Pipe fitters 1 Certified welder 2 Laborers	

C-24

UNIT: Centrifugal Compressor

DESCRIPTION: 2500 hp, integral gear, 4 casings, 3 intercoolers and interconnecting piping, motor drive

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Small control piping ruptured, gauges smashed and inoperable	Missile, drag & diff.	2.0	3.0	4.0	1	2		Pressure gauges Temp. indicators pipe, tubing	2 Pipe fitters	Manual operations required
Inlet and outlet pipes sheared off at connection to compressor	Drag	8.0	9.0	10.0	22	[illegible]	Crane	Pipe	2 Riggers 2 Pipe fitters 2 Millwrights 2 Welders 1 Equipment operator	
Compressor displaced off mountings, mounting bolts sheared, severe deformation and rupturing of all external piping	Diff. & drag	72.0	[illegible]	30.0	47	30	Compressor Jack hammer Crane	Grout Foundation bolts Dollyway shaft Coupling Bearings	2 Laborers 1 Jackhammer operator 5 Riggers 2 Millwrights 2 Pipe fitters 2 Welders	

C-26

UNIT: Barometric Condenser

DESCRIPTION: 5 ft diameter by 8 ft high on straight side, 107 ft^3 - mounted 58 ft above grade - 3 in. tail pipe - 1-1/2 in. steam - 3 in. water, 4 in. gas nozzle.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Control and monitoring gauges smashed, condenser shifts slightly on mounting	Diff. & drag	1.0	1.6	2.0	8	3	Crane Cutting torch Welder	Gauges Piping	1 Equipment operator 1 Welder 1 Pipe fitter 1 Ironworker	
Condenser overturns, rupturing all connections, some deformation of condenser shell, control piping is ruptured and monitoring gauges smashed	Drag	3.0	3.5	4.0	20	10	Crane Cutting torch Welder Scaffolding	Structural framing Rolled plate Gauges Piping Insulation	2 Welders 2 Equipment operators 2 Ironworkers 2 Pipe fitters 1 Certified welder 1 Insulator	

C-20 UNIT: Chlorine Gas Dryer

DESCRIPTION: 4 stages: 5 ft diameter by 20 ft high, 265 ft³; 10 in. inlet and 10 in. outlet; 1-1/2 in. acid inlet and outlet; 1-1/2 in. drain; filled with ceramic packing; liquid distributor; temperature indicator.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Outlet pipe separated from connection to drying tower; tower sections slightly cracked and some separation at bell and spigot joints	Drag	3.2	4.0	9.8	25	7	Rigging equipment, heating kettle and ladles or mops	Coal tar pitch; Pipe-flanges-ftgs. for drain line	2 Riggers 4 Laborers 2 Pipe fitters	
Tower overturns, severing all connections; five sections are separated and badly cracked	Drag	6.0	6.5	7.0	40	7	Rigging equipment; Truck	New tower sections incl. cap; New packing, pipe, pipe-flanges-ftgs.	3 Riggers 1 Truck driver 2 Pipe fitters 2 Masons	

193

C-27

UNIT: Centrifuge

DESCRIPTION: 30 hp, 3 in. inlet, 3 in. outlet, (3) Misc. 1 in. conn.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Small control piping ruptured	Missile & drag	3.0	3.0	4.0	3	3		Pipe Press gauges Thermometers	1 Pipe fitter	Manual operation required
Feed pipe sheared at connection to centrifuge	Drag	8.0	8.8	9.6	7	5	Oxy-acetylene torch Welding mach.		2 Welders 2 Pipe fitters	
Mounting bolts shear and centrifuge moves off mounting, all connections sheared, unloading mechanism jammed and damaged	Diff., drag & missile	15.0	18.7	22.3	24	13	Crane	Expansion bolts Unloading mech. parts Wire Grout	1 Laborer 2 Riggers 2 Millwrights 1 Electrician 2 Welders 2 Pipe fitters	Unit inoperable

UNIT: Hooker Type Electrolytic Cell

DESCRIPTION: Concrete tub and cover individual units 0 ft by 0 ft by 0 ft, 1.15 tons per day Cl_2 capacity, 123 sq dm per cell.										
DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	90%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Concrete top suffers several cracks but otherwise stays intact, chlorine outlet pipe and brine feed pipe shear off at their connection to top of cell	Diff.	3.0	3.5	3.0	4	2	Rigging equipment Hoist Fork lift	Concrete cell top Misc. pipe fittings Misc. sealants	2 Riggers 2 Pipe fitters	Cell inoperable when displaced off mountings
Concrete top suffers brittle failure producing missiles which will be scattered throughout building with some concrete blown into cell, severely damaging all cathodes and anodes which would require replacement	Diff.	3.0	3.7	4.0	8	4	Rigging equipment Hoist Fork lift	Concrete cell top Misc. pipe fittings Misc. sealants Set of anodes Set of cathodes	2 Riggers 2 Pipe fitters	Factors affecting damage: o Shielding by other cells o Orientation to blast wave o Space between cells o Age of elements
Steel and concrete cell wall (perpendicular to blast wave) buckles and splits spalling interior concrete lining into cell damaging cathodes and anodes	Diff.	3.0	3.3	3.6	9	4	Rigging equipment Hoist Fork lift	Concrete cell top Cell wall unit Misc. sealants Set of anodes Set of cathodes Misc. pipe fittings	2 Riggers 2 Pipe fitters	

C-2A

UNIT: Hooker Type Electrolytic Cell (continued)

DESCRIPTION:

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Cell displaced off ceramic insulator mounting in direction of blast waves, mountings damaged and require replacement. Graphite anodes jarred out of slots in cell bottom, probable breakage to 20 percent of anodes which would require replacement. Cathodes would lose asbestos covering from impact and backwash of brine, requiring replacement. All connections to cell body sheared off at entrance into cell.	Diff.	0.0	?.?	9.0						The orientation of the 200 cells array to the blast wave can be accounted for. An example for an array of 3 cells long for every 1 cell wide would be: For a blast wave impinging on the short side of the cell array multiply overpressure figures on left by 0.9. For blast wave on the long side multiply overpressure figures by 1.1.

C-20

UNIT: Mercury Electrolytic Cell No. E1, Olin Mathieson Co. Type

DESCRIPTION: Shallow structural steel structure, rubber lined, 60 anodes per cell, 3.3 tons per day Cl_2 capacity.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Cover plate deforms causing several cracks in center of plate - 60 percent of porcelain anode insulators cracked and unusable	Diff. & missile	2.0	3.2	3.4	11	4	Cutting torch Welder Angle grinder Vulcanizing platens	Anode insulators Sheet rubber and other vulcanizing materials	2 Ironworkers 2 Millwrights 1 Welder 1 Vulcanizer	
Deformation of steel decomposer walls with some rupturing in center of walls	Diff.	3.0	3.3	3.6	10	6	Cutting torch Welder	Plate steel Graphite filler	2 Ironworkers 2 Millwrights 2 Welders 1 Vulcanizer 2 Pipe fitters	
Cl_2 + H_2 outlet pipes sheared off at entrance to cell top, intercell bus structure and anode adjustment structure severely deformed, 20 percent anode breakage	Drag & diff. & missile	6.0	7.5	9.0	26	10	Heating torch Cutting torch Welder	Copper bars and x's Anode insulators Anode adjusting rods and nuts	2 Pipe fitters 2 Ironworkers 1 Welder 2 Millwrights 1 Vulcanizer	
Cell displaced off mounting and tips over causing loss of mercury, support bolts sheared off, all connections to cell are broken and probable 60 percent anode breakage	Drag & diff.	15.0	18.7	22.4	36	10	Rigging tools Heating torch Cutting torch Welder	Copper bars and x's Anode insulators Anodes Anode adjustments Piping for Cl_2 and H_2 Mercury	2 Pipe fitters 1 Ironworker 1 Welder 2 Millwrights 1 Vulcanizer	

C-30

UNIT: Rotary Vacuum Filter

DESCRIPTION: 8 ft diameter drum, 4 ft wide, 78 ft², three 3-in. connections, three 1-in. connections, 25 HP chain drive.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
The filter grid on the blast loaded side is torn by missiles	Missiles & drag	2.0	2.3	2.5	9	5	Cutting torch Welder Grinder buffer Rigging equipment	Curved grid sections Rolled plate	2 Ironworkers 1 Welder 1 Pipe fitter	
Small control piping ruptured, gauges smashed and inoperable	Diff. & drag & missile	2.0	2.2	2.5	12	6		Control piping fittings Gauges	2 Pipe fitters 2 Ironworkers 2 Welder	Unit inoperable
Filter grid supporting framework on blast loaded side collapse into filter drum. Internal piping inside drum damaged by missiles	Drag & missile	4.0	4.4	4.8	17	7	Cutting torch Welder Grinder buffer Rigging equipment	Curved grid sections Rolled plate Flat plate Pipe-ftg.-flges.	2 Ironworker fitters 1 Welder 2 Pipe fitters	
Anchor bolts shear and rotary filter is shifted off its base, external piping connections shear	Drag	7.5	9.4	11.2	21	4	Rigging equipment	Bolts Pipe-flges.-ftgs	3 Ironworkers 1 Millwright 2 Pipe fitters 1 Welder	
Filter overturns, the filter drum is smashed, the filter tank is buckled, misalignment occurs between filter drive motor and shaft	Drag	10.0	12.5	15.0	35	9	Rigging equipment	Spare filter drum Rolled plates Flat plate Pipe-flges.-ftgs	2 Ironworkers 1 Millwright 1 Welder 2 Pipe fitters	

C-31 | UNIT: Screw Conveyor

DESCRIPTION: 12 in. diameter by 20 ft long fully enclosed, 1040 ft^3, - over flow on inlet-free discharge - 3 HP chain drive - mounted 3 ft above ground - 1/2 round bottom.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Sides and top of conveyor trough buckle inwards jamming flight conveyor (main screw feeder)	Diff. & missile	5.0	3.3	3.0	3	2	Cutting torch Welder	Rolled plate Plate plate	1 Ironworker 1 Welder	Unit inoperable
Flights (screw threads) are partially deformed	Diff. & missile	6.0	6.6	7.2	7	3	Cutting torch Heating torch Porta jack equipment	Rolled plate Flat plate	2 Ironworkers 1 Welder 1 Millwright	
Flight conveyor shaft suffers slight misalignment with countershaft gear box and is also misaligned with its hanger bearings	Diff. & missile	8.0	8.8	9.6	10	4	Cutting torch Heating torch Porta jack equipment	Rolled plate Flat plate	2 Ironworkers 1 Welder 1 Millwright	
Conveyor is displaced off its mountings when anchor bolts shear causing severe deformation of the shaft and conveyor flights, and severe buckling and rupture of trough	Drag	9.5	11.0	14.2	15	5	Cutting torch Heating torch Porta jack equipment Rigging equipment	Rolled plate Flat plate Section of replacement flight and trough	2 Ironworkers 2 Welders 1 Millwright	

C-32

UNIT: Clarifier

DESCRIPTION: 50 ft diameter steel tank, 30 ft high, 40,140 ft^3, - 2 sweep arms and blades mounted on center drive pedestal - bridge across tank bracing pedestal - 1/4 plate weir all around top of tank.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Tank uplifted on blast loaded side with bottom rupturing 1/2 of circumference along joint with shell plates; brine outlet pipe ruptured at connection to tank	Diff.	3.0	4.0	5.0	41	10	Cutting torch Welder Crane Rigging equipment	Rolled plates Flat plates Structural shapes Temporary structural posts and braces Pipe and figes bolts	4 Laborers 1 Pipe fitter 1 Certified welder 2 Ironworkers 2 Welders 2 Equipment operators	Clarifier inoperable
Drive motor and supporting mechanisms torn from supports causing deformation of driving shaft	Drag & diff.	8.0	9.0	10.0	82	15	Crane Cutting torch Welder	Flat plates Bolts Shafting Shaft couplings	4 Ironworkers 3 Welders 1 Millwright 2 Equipment operators 4 Laborers 1 Pipe fitter 1 Certified welder	

C-33 UNIT: Acid Coolers - 1200 sq ft - 10 sections high and 10 columns long

DESCRIPTION: 1250 sq ft of cooling surface, 10 sections in a column and 10 columns long, constructed of 1/2 in. cast iron, spray type cooler, each section is 48 in. by 15 in. high.

DAMAGE ESTIMATED					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Main inlet and outlet pipes to acid coolers rupture (2 breaks)	Drag	5.0	5.5	6.0	2	1		Joints of 4 in. flanged pipe	2 Pipe fitters	2 man-hrs per joint
Acid coolers shift slightly off base; two supporting columns reformed	Drag	7.0	7.7	8.4	8	2	Crane Rigging equipment Welding equipment	Joints of 4 in. flanged pipe Miscellaneous structural steel	2 Ironworkers 2 Pipe fitters 2 Equipment operators	Unbolt, reset, reframe and rebolt
Acid coolers overturn, cause rupturing of interconnection joints	Drag & missile	10.0	13.0	15.0	20	3	Crane Rigging equipment Welding equipment	Joints of 4 in. flanged pipe Miscellaneous structural steel Miscellaneous cooler sections	4 Pipe fitters 2 Ironworkers 2 Equipment operators	

C-34

UNIT. Package Refrigeration System

DESCRIPTION: (2) 100 hp compressors; (2) 100 hp motor drivers,
Motors coupled to compressors by flexible couplings

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Control gauges smashed and inoperable	Diff. & missile	2.0	2.2	2.5	3	1	None	Pressure gauge Temperature control valves Thermometers	2 Pipe fitters 1 Electrician	Specific damage to the prime mover of the refrigeration system is covered in Tables C-19 and C-26.
Control panel smashed and torn from its mountings, control wiring and piping is severed at the panel	Diff. & missile	6.0	6.2	7.0	13	6	Chain hoist	Motor starter Relays Contactors Tubing, wire Conduit	2 Pipe fitters 2 Electricians 2 Sheetmetal smiths	
Water connections to the lube oil cooler are severed	Drag & missile	7.0	7.7	8.5	10	6	Chain hoist	Pipe (plus all of above)	2 Pipe fitters 2 Electricians 2 Sheetmetal smiths	
Water inlet and outlet pipes to the cooler and condenser rupture	Drag & missile	13.0	14.3	15.6	21	8	Oxy-acetylene torch Chain hoist	Pipe (plus all of above)	1 Certified welder 1 Welder 2 Pipe fitters 2 Electricians 2 Sheetmetal smiths	
Misalignment between compressor and prime mover	Diff.	22.0	24.2	26.4	33	8		Shim stock (plus all of above)	1 Certified welder 1 Welder 2 Pipe fitters 2 Electricians 2 Sheetmetal smiths 2 Millwrights	

E-29

UNIT. Automatic Regenerative Liquid or Gas Dryer

DESCRIPTION. 250 CFM, 100 psig, Air Drier, 10 in. diameter, 8 ft high

DAMAGE ESTIMATES					REPAIR ESTIMATES					COMMENTS
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN DAYS REQD.	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	
							CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
		5%	50%	95%						
Control gauges smashed and inoperable	Diff. & missile	3.0	3.8	9.4	4	2		Pressure gauge Humidity controller	1 Pipe fitter 1 Electrician	Manual operation required
Control panel severely deformed and torn from its mountings, control wiring and piping is severed at panel connections	Diff. & missile	5.0	6.2	7.6	8	3		Pressure gauge Humidity controller Wire Conduit Tubing	1 Pipe fitters 1 Electricians 1 Sheetmetal smith	Unit inoperable
Fifty percent of small external piping is ruptured	Drag & missile	8.0	8.8	9.8	8	3		Pressure gauge Humidity controller Wire Conduit Tubing Pipe	1 Pipe fitter 1 Electrician 1 Sheetmetal smith	
Dryer overturns, all inlet and outlet pipes are ruptured	Drag	9.0	9.0	10.8	8	4	Welding machine Oxy-acetylene torch	Pressure gauge Humidity controller Wire Conduit Tubing Pipe	1 Pipe fitter 1 Certified welder 1 Welder 1 Electrician 1 Sheetmetal smith	

C-30 UNIT: Control Cubicles

DESCRIPTION: 4 ft wide section, 7 ft 6 in. high; two PPS; two LRC; two TSC; four FRC; Pneumatic instruments.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Meters broken and inoperable; shafts bent and indicating area badly deformed	Diff. & missile	1.0	1.0	8.0	7	6		Pressure controllers Level controllers Temperature controllers Flow controllers	1 Pipe fitter 1 Electrician	Manual operation of processes required
Electrical connections severed, pneumatic control lines ruptured requiring replacement, panel board deformed	Diff. & missile	2.4	5.0	8.0	17	10		Pressure controllers Level controllers Temperature controllers Flow controllers Tubing Wire	1 Pipe fitter 1 Electrician 1 Sheetmetal smith	
Control cubicles completely destroyed and requires replacement	Diff. & missile	6.0	6.9	7.5	18	13	Oxy-acetylene torch	Pressure controllers Level controllers Temperature controllers Flow controllers Tubing Wire	1 Pipe fitter 1 Electrician 2 Riggers 1 Welder 1 Laborer	

C-37

UNIT: Piping and Pipe Racks

DESCRIPTION: One 40 ft long section of pipe, rack 22 ft wide, 17 ft off ground, 1200 ft^3, ~ double decker ~ 8 in. Hvy. 'H' column legs ~ 12 in. beams

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Deformation of supporting column	Drag	4.0	5.0	6.0	16	3	Cutting torch Welder Crane Cribbing	Structural shapes	3 Ironworker 2 Welders 2 Crane operators	
Supporting column fail through column buckling and pipe rack and pipes collapse onto ground	Drag	4.0	7.0	9.0	10	17	Crane Cutting torch Welder Cribbing	Structural shapes Pipe Insulation material	2 Ironworkers 2 Ironworker welders 2 Equipment operators 4 Pipe fitters 2 Certified welders 3 Insulators	

A-1 UNIT: Gas Service Motor

DESCRIPTION: A Roots-Connorsville type industrial gas service motor, mounted free standing, above ground in a small outdoor control complex.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Dials and glass sight glass for oil level are smashed	Diff.	3.0	3.2	3.4	1	1		Small pipe & fittings	1 Pipe fitter	
Case cracked from strain exerted by connecting pipe	Missile & drag	4.0	4.4	4.8	3	2		Gasket sets & materials Seals Packing	1 Pipe fitter 1 Laborer 1 Instrument repairman	

A-2 UNIT, Gas Service Regulator

DESCRIPTION: A Fisher type industrial gas service regulator, gas operated, pilot type, mounted free standing, above ground in a small outdoor control complex.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Small external piping and components broken loose causing leaking	Drag & missile	5.0	6.2	7.5	1	1		Small pipe & fittings	1 Pipe fitter	
Small piping and regulator causing damaged regulator valve severely deformed	Drag & missile	8.0	10.0	12.0	2	2		Gasket sets & materials Small pipe & fittings Seals Packing	1 Pipe fitter 1 Laborer 1 Instrument repairman	

A-3

UNIT: 10 MVA Transformer

DESCRIPTION: Westinghouse BL core form type 60 cycle, 3 phase, free standing mounted on rails, tube type radiator system

DAMAGE ESTIMATES					REPAIR ESTIMATES					COMMENTS
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Twenty-five percent of radiator tubes are deformed and rupture causing severe transformer oil leakage	Drag	4.0	4.5	5.0	30	6	Welding & cutting equipment Crane	Tubing	3 Electricians 1 Rigger 1 Equipment operator	Transformer inoperable
Power connections to transformer broken, porcelain bushings broken and unusable; insulators destroyed	Missile & drag	7.0	7.7	8.4	75	9	Welding & cutting equipment Crane	Tubing Bushings Insulators	7 Electricians 1 Equipment operator 1 Rigger	
Transformer overturned, radiators ruptured on one side, cover displaced with probable winding damage	Drag	8.0	10.0	12.0	125	12	Welding & cutting equipment Crane	Tubing Bushings Insulators Radiators	7 Electricians 2 Equipment operators 3 Riggers	

A-4

UNIT: Bus Structure and Switchgear

DESCRIPTION: 34 kv rated, steel tubular construction with two 500 MVA circuit breakers and associated disconnects and insulators.

DAMAGE ESTIMATES					REPAIR ESTIMATES					COMMENTS
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Permanent deformation	Drag & missile	4.0	4.5	5.0	11	4	Crane	Copper bus Steel tubing Insulators Bushings	5 Electricians 2 Equipment operators	
Bus structure partially collapsed and small circuit breakers overturned		5.0	6.2	7.5	30	6	Crane Cutting torch Welder	S.A.A.	4 Electricians 2 Equipment operators	
Bus structure fully collapsed, most insulators broken and disconnects deformed		6.0	7.7	9.5	60	10	Crane Cutting torch Welder	S.A.A. Disconnects	4 Electricians 2 Equipment operators	

A-5

UNIT: Rectifier

DESCRIPTION: 20 ft by 10 ft by 10 ft metal cubicle, water cooled silicon rectifier rated at 40 KA - 700 VDC

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	90%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Control panel meters broken and inoperable, shafts bent and indicating arms deformed; rectifier cubicle moderately deformed	Diff. & missile	2.0	2.5	3.0	6	3	Cutting torch Heating torch Welder Porter jack equipment Rigging equipment	Meters Indicator shafts	1 Ironworker 1 Welder 2 Electricians	
Rectifier cubicle overturns rupturing cooling system; silicon rectifiers displaced from their mountings, bus connections broken and cubicle badly deformed; control panels severely damaged and requires replacement	Drag, diff. & missile	3.0	3.75	4.5	72	23	Cutting torch Heating torch Welder Rigging equipment Porta jack equipment	Miscellaneous iron New control panel New silicon rectifier units Piping Coolant	1 Certified welder 2 Pipe fitters 2 Ironworkers 6 Electricians	
Rectifier cubicle destroyed and requires replacement	Drag, diff. & missile	6.0	7.5	9.0	103	20	Cutting torch Welder Rigging equipment Porta jack equipment Crane	New cubicle New control panel New rectifier	6 Electricians 2 Ironworkers 1 Pipe fitter 2 Equipment operators	

A-8 UNIT: Vertical Filter

DESCRIPTION: 4 ft diameter by 8 ft high vertical sand filter with 4 in. intake and exit pipes.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Small control piping ruptured	Missiles & drag	2.0	3.0	4.0	3	2	Cutting & welding equipment	Small piping & fittings	2 Pipe fitters	Manual operation required
Inlet and outlet pipes broken at the connection to filter body	Drag	8.0	9.0	10.6	23	7	Cutting & welding equipment	Small piping & fittings Pipe & flanges	2 Pipe fitters 1 Certified welder 1 Welder	Filter inoperable until connections repaired
Mounting bolts shear and filter overturns, all connections sheared off, some deformation of filter tank body	Diff. & drag	12.0	14.0	10.0	29	9	Cutting & welding equipment Crane Rigging equipment	Small piping & fittings Pipe & flanges Bolts Flat plates	2 Pipe fitters 1 Certified welder 1 Equipment operator 1 Rigger 1 Millwright	

A-7

UNIT: Elevated Water Tank

DESCRIPTION: 5 ft diameter by 10 ft high, 140 ft³, mounted 30 ft above grade, 3 in. inlet pipe.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Roof collapsed into tank	Diff.	1.0	1.5	2.0	8	4	Crane Cutting torch Welding equipment	Flat plate Structural shapes	2 Welders 2 Ironworkers 1 Equipment operator	Conical or flat top roof
Tank - empty - tank overturns and collapses onto ground	Drag	2.5	3.0	4.0	20	8	Crane Cutting torch Welding equipment	Flat plate Structural shapes Rolled plate Piping Flanges	2 Welders 2 Ironworkers 1 Equipment operator 1 Pipe fitter 1 Certified welder	
Tank - full - supporting columns deform, connections to tank are broken	Drag	3.0	3.75	4.5	20	8	Crane Cutting torch Welding equipment	Flat plate Structural shapes Rolled plate Piping Flanges	2 Welders 2 Ironworkers 1 Equipment operator 1 Pipe fitter 1 Certified welder	
Tank - full - supporting columns buckle, tank overturns onto ground	Drag	4.0	5.0	6.0	20	10	Crane Cutting torch Welding equipment	Flat plate Structural shapes Rolled plate Piping Flanges	2 Welders 2 Ironworkers 1 Equipment operator 1 Pipe fitter 1 Certified welder	

A-8

UNIT: Package Boiler Unit

DESCRIPTION: 11 ft 0 in. by 20 ft by 10 ft high = 50,000 lb/hr = 7 by 10^7 Btu/hr, gas fired boiler with bare tube economizer and feed water regulator, soot blowers and forced draft fan.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED			COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS	LABOR SKILLS REQUIRED	
Gauges smashed and inoperable, small control piping ruptured	Diff., drag & missile	2.0	2.2	2.5	8	3		Steel tubing Pressure gauges Level controller Damper controller Gauge glasses Wire	2 Pipe fitters 1 Electrician	
Flue crushed and ruptured	Diff. & missile	2.4	3.0	3.0	10	9	Crane Jacks Oxy-acetylene torch Welding machine	Steel tubing Pressure gauges Level controller Damper controller Gauge glasses Wire Plate	1 Equipment operator 2 Riggers 1 Certified welder 1 Welder 2 Pipe fitters 1 Electrician	
Boiler sides buckle, some distortion of side wall tubes, and refractory is cracked	Diff. & missile	4.0	4.4	4.8	44	21	Crane Jacks Oxy-acetylene torch Welding machine Tube rolling equipment	Steel tubing Pressure gauges Level controller Damper controller Gauge glasses Wire Plate Tubes Fire brick	1 Equipment operator 2 Boilermakers 1 Mason 3 Laborers 1 Welder 1 Certified welder 2 Riggers	
Anchor bolts fail and boiler is displaced on fittings and overturns, all connections broken, boiler tubes deformed	Drag, diff. & missile	7.0	7.7	8.4	115	33	(all of the above)	(all of the above Pipe Tubes Wire Gaskets Bolting Flanges Steel plate Safety valves Anchor bolts	plus following) 1 Electrician 2 Millwrights 2 Boilermakers 1 Mason 3 Laborers 1 Welder 1 Cutter 2 Pipe fitters 1 Equip. oper.	

A-9

UNIT: Prefab Building

DESCRIPTION: A 5800 ft² modular, prefab, commercial mill building type with sheet steel panels and separate structural steel framework and crane support.

DAMAGE ESTIMATES					REPAIR ESTIMATES					
DAMAGE DESCRIPTION	CAUSE OF FAILURE	PROBABILITY OF FAILURE AT GIVEN OVERPRESSURE			MAN-DAYS REQD	TIME REQD (DAYS)	RESOURCES REQUIRED		LABOR SKILLS REQUIRED	COMMENTS
		1%	50%	99%			CONSTRUCTION OR REPAIR EQUIPMENT	SUPPLIES AND SPARE PARTS		
Fifty percent of roofing and side panels are damaged or torn off	Diff.	1.2	1.5	1.8	9	2	Welding & cutting equipment	Fasteners Sheet metal Clips	5 Ironworkers	
All roofing and siding stripped off, steel frame distorted	Diff.	2.0	2.5	3.0	40	10	Welding & cutting equipment	Fasteners Sheet metal Clips	5 Ironworkers	
Building completely destroyed, only foundation intact	Drag	6.0	7.5	9.0	93	13	Welding & cutting equipment Crane	New prefab building	5 Ironworkers 1 Rigger 1 Crane operator	

APPENDIX F

DISTRIBUTION

DAMAGE TO THE BASIC CHEMICAL INDUSTRY FROM NUCLEAR ATTACK AND RESULTANT REQUIREMENTS FOR REPAIR AND RECLAMATION (U) URS 687-4

URS Systems Corporation, Burlingame, California
June 1968 180 pp. Contract No. 12475(6300A-300)
Work Unit 3311B

UNCLASSIFIED

This study identifies the major equipment components commonly used by industries of the basic chemicals group [Standard Industrial Classification (SIC) 281], estimates damage to the equipment components as a result of various nuclear weapon effects, and estimates the consequent repair requirements. Case studies for selected industries were synthesized by assembling the damage and repair estimates for the equipment components of various chemical establishments. These estimates were then scaled up to represent damage/repair for the selected chemical industries. Mathematical models were developed to relate repair effort with damage level for the individual equipment, establishments, industries, and the overall basic chemical industry group. From the output of the models, time-phased repair effort (with delineation of manpower by skills) was derived.

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3. REPORT TITLE

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4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report

5. AUTHOR(S) (Last name, first name, initial)

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Milton Staackmann

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This study identifies the major equipment components commonly used by industries of the basic chemicals group, (Standard Industrial Calssification (SIC) 281), estimates damage to the equipment components as a result of various nuclear weapon effects, and estimates the consequent repair requirements. Case studies for selected industries were synthesized by assembling the damage and repair estimates for the equipment components of various chemical establishments. These estimates were then scaled up to represent damage/repair for the selected chemical industries. Mathematical models were developed to relate repair effort with damage level for the individual equipment, establishments, industries, and the overall basic chemical industry group. From the output of the models, time-phased repair effort (with delineation of manpower by skills) was derived.

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Chemicals						
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Damage Assessment						
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